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THESIS

A COST ESTIMATION MODEL FOR THE
SEA LAUNCH AND RECOVERY
SPACE TRANSPORTATION SYSTEM

by

Layne Renée Boone

September, 1990

Thesis Co-Advisors: Michael Melich
Dan C. Boger

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The purpose of this thesis is to provide a cornerstone for the design of such a cost estimation model. The model presented here can be used to compute the minimum cost per mission as a function of selected design variables. The particular variables considered are the type or types of materials used in the fuel tanks of the rocket and characteristics of the fuel logistics, such as port locations. Thus, it is a tool to be utilized by the system designers in judging the value of particular rocket fuel tank designs. It can also aid in the selection of the operational port for the system.

Implementation issues are discussed and evaluated. Future enhancements to the model are also discussed.

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A Cost Estimation Model for the Sea Launch and Recovery Space Transportation System

by

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ABSTRACT

The Sea Launch and Recovery Space Transportation System is envisioned as a means of achieving not only more effective but lower cost space operations. The development of a cost estimation model is important in determining the feasibility of this system.

The purpose of this thesis is to provide a cornerstone for the design of such a cost estimation model. The model presented here can be used to compute the minimum cost per mission as a function of selected design variables. The particular variables considered are the type or types of materials used in the fuel tanks of the rocket and characteristics of the fuel logistics, such as port locations. Thus, it is a tool to be utilized by the system designers in judging the value of particular rocket fuel tank designs. It can also aid in the selection of the operational port for the system.

Implementation issues are discussed and evaluated. Future enhancements to the model are also discussed.

THESIS DISCLAIMER

The reader is cautioned that the computer program developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the program is free of computational and logic errors, it can not be considered valid. Any application of this program without additional verification is at the risk of the user.

TABLE OF CONTENTS

I. INTRODUCTION

The Naval Center for Space Technology of the Naval Research Laboratory is conducting a research and development program into the properties of a family of reusable rockets that are launched from the ocean. The feasibility of a space transportation system using these Sea Launch and Recovery (SEALAR) rockets is of interest to the Secretary of the Navy, the Director of the Navy Space Systems Division of the Office of the Chief of Naval Operations , and the Senate Armed Services Committee. Such a space transportation system, henceforth to be referred to as the SEALAR Space Transportartion System (SSTS), could be used to provide military and commercial access to space under either war or peacetime conditions from the ocean. Space access would not be limited by the restrictions now placed upon land-based launch sites.

The SSTS was first conceived in the late 1950's. In the 1960's it received extensive study by Aerojet General under a contract to NASA's Marshall Space Flight Center. A series of new detailed investigations was initiated in February 1988 by the Naval Center for Space Technology. The technical feasibility of rocket recovery without extensive damage to the rocket stages, hence reusability, is currently under study. However, the economic competitiveness of the SSTS hinges on more than reusability. It also depends on total research and development and operational costs. [Ref. 1]

The SSTS is a system being designed to provide low cost-per-mission, low cost-per-pound orbited, and a known service delay for its users. In order to

successfully accomplish these objectives, the designers need mathematical tools to aid them in their analyses.

It is the intention of this thesis to provide a design for a means for judging the value of particular rocket fuel tank designs. This tool can then be used by the SSTS designers to assess those costs for their potential customers. It will also be useful in determining which port of operation would be most cost efficient in terms of these fuel tank costs and the port operating costs. This model will be a cornerstone upon which a complete SSTS cost estimation model can be built. The conceptual basis for this tool was provided by the major developers of the SSTS, Truax Engineering, Inc.

The second chapter deals with the background of the SEALAR Space Transportation System. The motivation for this type of space transportaion system is discussed. The SSTS is described followed by the history of the SEALAR rockets.

Chapter III presents the concept of operations of the SSTS. This involves describing the relationships between the operational functions of the system.

The fourth chapter describes the optimization model used to minimize the cost of the SEALAR rocket fuel tanks for the SSTS. It is the tool with which the SSTS designers can readily determine which fuel tanks are most cost efficient. It also can be used to determine the most cost efficient port of operation since it provides the cost per mission of operating at each port based on these fuel tank costs and the port operating costs.

Chapter V is an analysis of the fuel tank and operating cost estimation model. Variations of the model are discussed and analyzed.

II. BACKGROUND

A. MOTIVATION

The military is a major developer and user of space. Its missions include space support in environment, navigation, communication, and surveillance. Space control and space warfare are also of paramount importance to military strategists. In this regard, there is a national need for not only more effective but lower cost space operations.

There are three possible ways in which to achieve this goal. The first is to reduce the cost of the space transportation system. Although a reduction in cost per launch could be realized by reducing the transportation system cost, this may require several launches to recoup the initial investment made during the development of such a system. This inevitably leads to the question of how many launches will be required in the forseeable future, a question which may be difficult to answer. The second alternative is to reduce the cost of the satellite. There is no evidence to date that this can be accomplished because of the reliability constraints which face the satellite engineers. However, if it were possible to carry more weight to orbit at a lower cost and to go to orbit at any time to repair or replace satellites, then the building of a cheaper satellite would become feasible. This leads to the third alternative, reducing the cost of both the satellite and the space transportaion system. The Sea Launch and Recovery Space Transportation System is a possible means of accomplishing this goal.

The Sea Launch and Recovery Space Transportation System (SSTS) was originally conceived and its development is currently being studied by the Naval

Center for Space Technology. These studies are based on the premise that a major reduction in space launch costs can be attained at a reasonable research and development cost. The motivation for these studies, at least in part, is the possibility that a reasonably effective defense against intercontinental ballistic missles (ICBMs) will also require that large amounts of equipment be placed in earth orbit. The SSTS could also provide transport to orbit for non-strategic defense missions or to locations on the earth along suborbital trajectories. It could be used for commercial as well as military satellite launches under conditions of peace and war. Some of the payloads for which the SEALAR Space Transportation System could be used for economically competitive transport are:

- satellites of 10,000 lbs and up being launched into earth orbi'
- cargo in support of space exploration missions, such as fuel for a planetary exploration program
- ordnance delivery for AAW, ASW, ASUW, strike and amphibious missions of the U. S. Navy
- urgently needed cargo to distant points on the earth.

If the cost could be reduced sufficiently, a large, reusable space launch vehicle would also have the ability to serve as a non-nuclear ICBM.

B. DESCRIPTION OF THE SSTS

The SEALAR Space Transportation System is composed of two subsytems: the rocket subsystem and the support subsystem. The rocket subsystem is based on a family of liquid-fueled, ocean-launched and recovered rockets. The support subsystem can be briefly defined as that part of the SSTS which encompasses the reception and preparation of the payload, the transport of the mated rocket to the

launch site, the actual launching of the rocket and its tracking and safety control during flight as well as the rocket recovery and refurbishment.

It is the ocean-launch capability that would eliminate several of the constraints and costs now associated with land-based launch. There would be less concern for launch pad vulnerability and/or survivability since the launch platform would be mobile and less susceptible to such damage. In addition, since the launch would be from open ocean, range safety concerns such as overflight of populated areas would be far less stringent than on land. By design, there would be limited environmental impact. Unlike land-based launches, the weather conditions during a SSTS launch could range from heavy to benign seas, winds, and precipitation.

The SSTS would also be advantageous because of its potentially low cost. This cost is a function of the fuels and rockets utilized. Reduced costs would be a result of the use of rockets that are recoverable and refurbishable. The fuels utilized by the SSTS can be easily replenished without major refurbishment to the rocket. Additionally, these propellants are not only inexpensive but environmentally safe and plentiful. This contributes to the effectiveness, in addition to the economy, of the system.

C. ROCKET SUBSYSTEM

In the early sixties, cost was a dominant consideration as the National Aeronautics and Space Administration (NASA) looked for ways to make a manned mission to Mars and a manned lunar base economically feasible. Two important conclusions were reached regarding the root causes of the high cost of space transportation. The first of these was that costs vary only slowly with size, but very sharply with complexity and reliability. The other was that a large fraction of the

cost of a space launch vehicle resided in the propulsion hardware that was discarded. [Ref. 2]

Based on the philosophy that a low-cost launch vehicle, therefore, should be big, simple, reusable, and use existing state of the art technology wherever possible, Aerojet-General Corporation conducted a project. This project resulted in a design that had the lowest cost predicted for any configuration. The design was dubbed the Sea Dragon and cost less than one hundred dollars per pound of payload delivered to orbit (in FY1963 dollars). The economy of the Sea Dragon was obtained not through ever-increasing sophistication but through its great size, simplicity, and reusability. [Ref. 2]

The Sea Dragon was of a size large enough to fulfill all of the foreseen missions. Its design embodied those characteristics required of a low-cost vehicle:

- It was big; it was capable of lifting to low orbit nearly one million pounds of payload per flight.

- It was simple; only two pressure-fed stages were used to attain low earth orbit (LEO). Each stage had only one main propulsion engine. Propellants used in the first stage were kerosene and liquid oxygen, in the second, oxygen and hydrogen.

- It was reusable; the simplest and lightest means available to return the stages to earth were used: a parachute-like drag device on the first stage, and a heat shield plus drag device on the second.

- It was sea launched; it was built in a drydock, towed to a lagoon, checked out dockside, fueled at sea, erected by a flooding ballast, and launched directly out of the water.[Ref. 3]

A small fleet of Sea Dragons would be capable of satisfying, in an economic fashion, all of the major space missions seriously considered to the current date, including the manned space station, the orbiting solar power station, a manned lunar base, and the Manned Mission to Mars.

Truax Engineering designed a pressure-fed, liquid propellant rocket called the Excalibur in the seventies. The Excalibur is a smaller version of Sea Dragon, having a liftoff weight of 3.6 million pounds and a payload of 100,000 pounds.

To reduce some of the design and competitiveness issues raised by the Sea Dragon launch vehicle concept, Truax Engineering was commissioned by the Naval Center for Space Technology to do a design study in 1988 of an even smaller version of the Sea Dragon. This new design, the SubCalibur, is only one-eightieth the size of Sea Dragon but is large enough to carry the largest Navy payload expected in the next ten years, and it embodies most of the technical features of Sea Dragon.

The SubCalibur rocket is a two-stage launch vehicle designed for minimum whole life cost over a ten year life. The first stage employs liquid oxygen and kerosene while the second stage employs liquid oxygen and liquid hydrogen. Both stages are pressure-fed with a single main engine per stage and both are recoverable in the ocean by drag devices only. The SubCalibur has the capability of launching 10,000 pounds of payload into low earth orbit (LEO) from land or sea. [Ref. 1]

Recently, Truax Engineering, in cooperation with the Naval Center for Space Technology, developed three near scale models of the first stage of an operational vehicle incorporating the design philosophy and most of the design features of the Sea Dragon, the X-3, X-3A and X-3B. The X-3 uses the same propellants, the same tank materials, but a different recovery system as proposed for the fully operational vehicle. Use of the X-3 will help to verify the design features of a water-launched, reusable first stage and, through repeated launches and recoveries, provide experience from which more accurate estimates of turn-around costs may be made. The X-3A and X-3B, redesigned versions of the X-3 rocket, are more faithful scale

models of SubCalibur and use high speed recovery. There are also plans for test vehicles larger than the X-3 family but smaller than Excalibur. [Ref. 1]

The Sea Launch and Recovery Space Transportation System is based upon the family of rockets comprising those just described. The SEALAR rockets will be used to determine the effectiveness of this transportation system in terms of cost per pound of payload delivered reliably to the desired destination. The cost per mission will also be used to define the system's feasibility.

III. OPERATIONAL CONCEPT

The operational concept, introduced by Aerojet-General Corporation in the form of the Sea Dragon and being further developed by NRL and Truax Engineering, basically uses mature technology in new ways. These new techniques include but are not limited to:

- economically launching from a floating position in the ocean
- ballistic recovery in the ocean at speeds up to perhaps as high as 300 feet per second with reusability of recovered components
- use of maraging steel or other high strength materials for tankage.[Ref. 1]

Sea launch is favored due to the ability to handle very large vehicles by exploiting buoyancy. It also provides great flexibility in launch location. In a military situation, this flexibility gives greater utility and lowered vulnerability to enemy countermeasures.

The Sea Launch and Recovery Space Transportation System will consist of a two-stage rocket where the second stage is capable of going on orbit. The vehicle will be prepared dockside with fueling dockside, at sea, or a combination of the two. After dockside checkout, the rocket is towed to sea by one or more tugs.

Following the erection of the rocket by flooding the ballast, it is launched from the ocean near the continental United States. The first stage will land less than two hundred miles down range after a ballistic reentry. It is subsequently retrieved by a tug and returned to the launch point for refurbishment and reuse.

The second stage will separate from its payload, make several orbits of the earth until it is in a favorable position, and then de-orbit at the proper time to enable impact less than two hundred miles from the launch site. A drag device and a relatively

small amount of heat protection is all that would be required to accomplish this. The second stage is retrieved from the ocean in the same manner as the first. Turn-around times on the order of a few days do not seem impossible for this launch vehicle since liquid propellant rockets should be more easily refurbished than solid propellant rockets.

This concept of operations for the Sea Launch and Recovery Space Transportation System can be depicted using the structured analysis flowchart technique. This is a technique by which a system is broken down into successively smaller, well-defined modules. [Ref. 4]

The top diagram in Figure 1 establishes the model of the launch service operation of the SSTS. The viewpoint taken is that of the SSTS operations manager. The operations manager is faced with several tasks based upon a customer's request. These include, but are not limited to, the number of rockets required to deliver the specified payload into the desired orbit, the amount of fuel required for the particular type of rocket, and the amount of time required to perform all of the necessary operations prior to and following the launch. In order to accomplish his tasks, the operations manager needs to know the customer's requirements (C1) as well as rocket requirements (C3). Space launches must also proceed according to specific launch procedures (C2).

Transporting a payload to orbit involves five major operations as depicted at the bottom of Figure 1. The first and certainly one of the most important steps is the interpretation of the customer's requirements (A1). Once these have been determined, the operations manager must determine the "cargo" necessary to accomplish the customer's mission. Table 1 illustrates some possible components of the "cargo". It is then the responsibility of the operations manager to transport the

cargo to the marshalling site (A3) after its arrival at the port (A2). Once the payload is actually launched (A4), the rockets must be recovered and refurbished (A5) in preparation for subsequent launches.

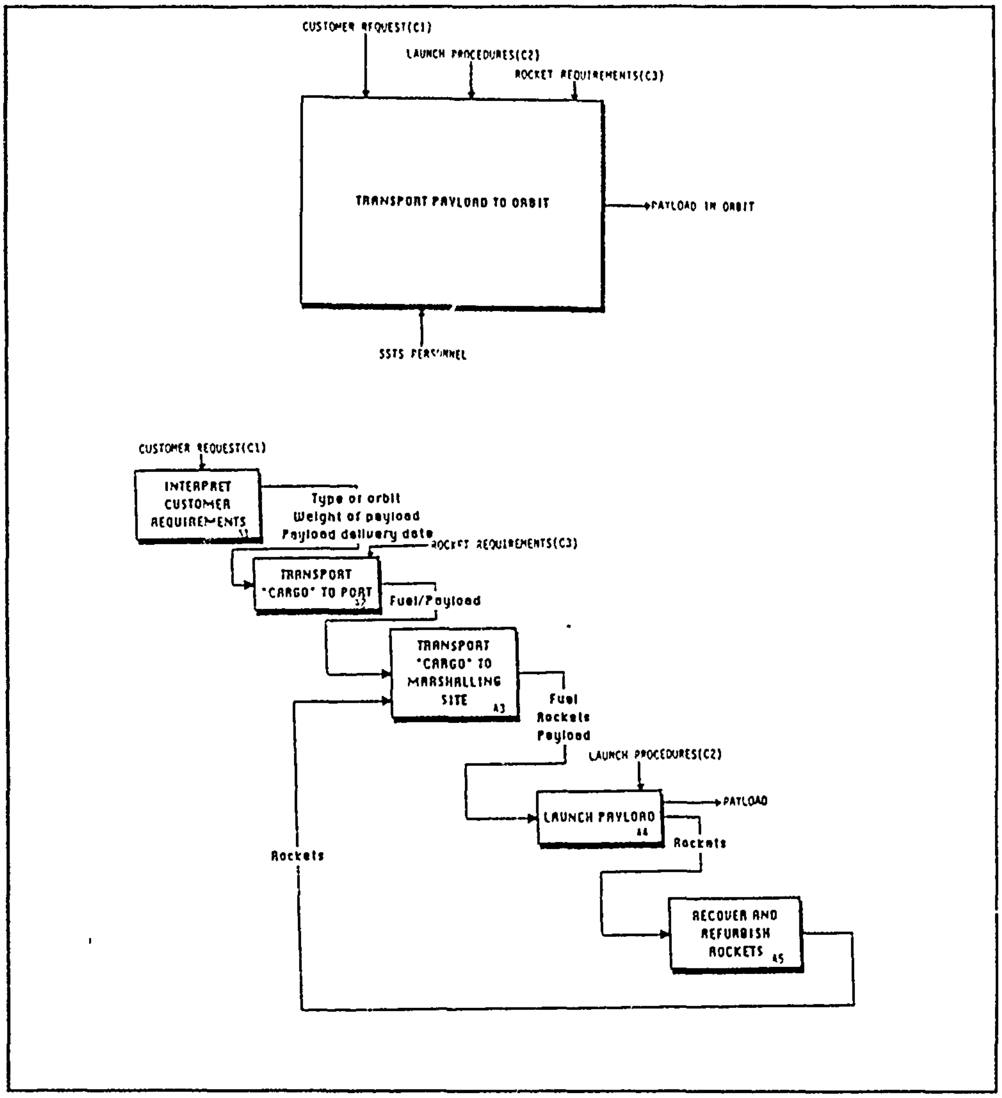

Figure 1: Transport Payload to Orbit

TABLE 1

EXAMPLE OF "CARGO" FOR LAUNCH OPERATIONS

CARGO FOR LAUNCH OPERATIONS
Customer Items
Payload
Special Telemetry/Communications
People
Special Fuels
Checkout Instrumentation
Rocket Subsystem Items
Fuels
People
Checkout Equipment
Tools
Support Subsystem Items
Fuel Trucks
Ballast Equipment
People

The customer's requests must be interpreted in order to develop a contract which specifies the weight of the payload to be delivered, the desired type of orbit and the desired payload delivery date. This contract will also have to specify the date on which the payload will be delivered to the port, as that will be the responsibility of the customer. These components of the A1 operation are depicted in Figure 2.

The contract established with the customer will be a major factor in determining what cargo is essential in accomplishing the mission. As shown in Figure 3, the engineers must determine the number and types of rockets required for the mission based on the weight of the payload and type of orbit desired, in addition to predetermined rocket requirements. The number and type of rockets will be the factors used in computing the amounts and types of fuels as well as the number of trucks required to transport the fuels to the port. The amount of fuel will be affected

by the time delay between when the rockets are fueled and when they are launched, due to burn-off. The personnel required to assemble the rockets is also a function of the number and type of rockets. All of this cargo must be transported to the port (A2). The time of arrival to port of the cargo trucks will be dependent upon the speed of the trucks and the distance from the fuel production location to the port.

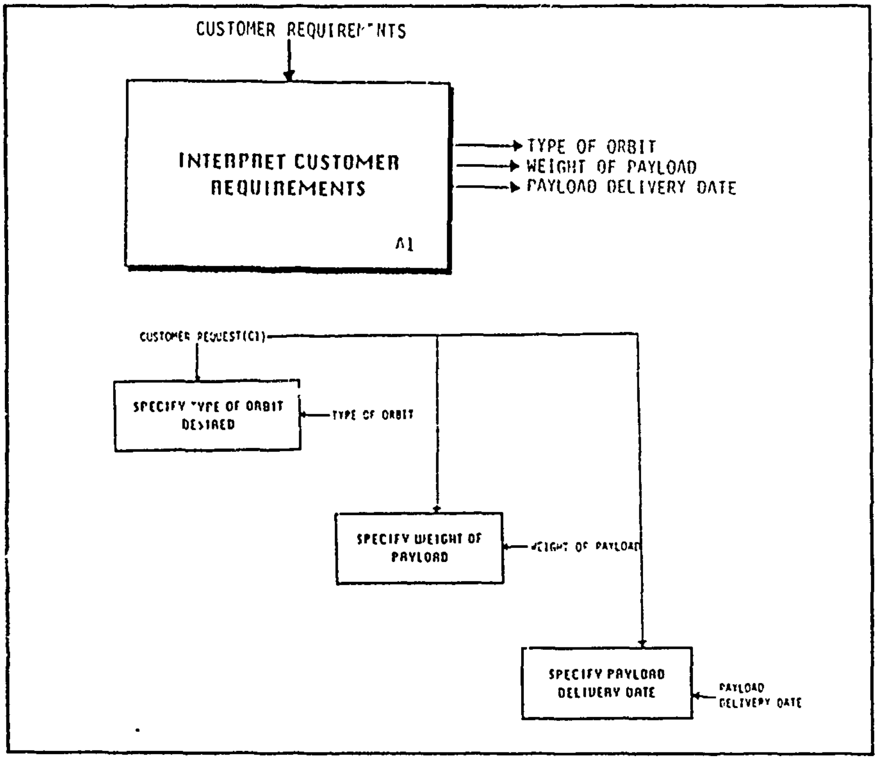

Figure 2: Interpret Customer Requirements (A1)

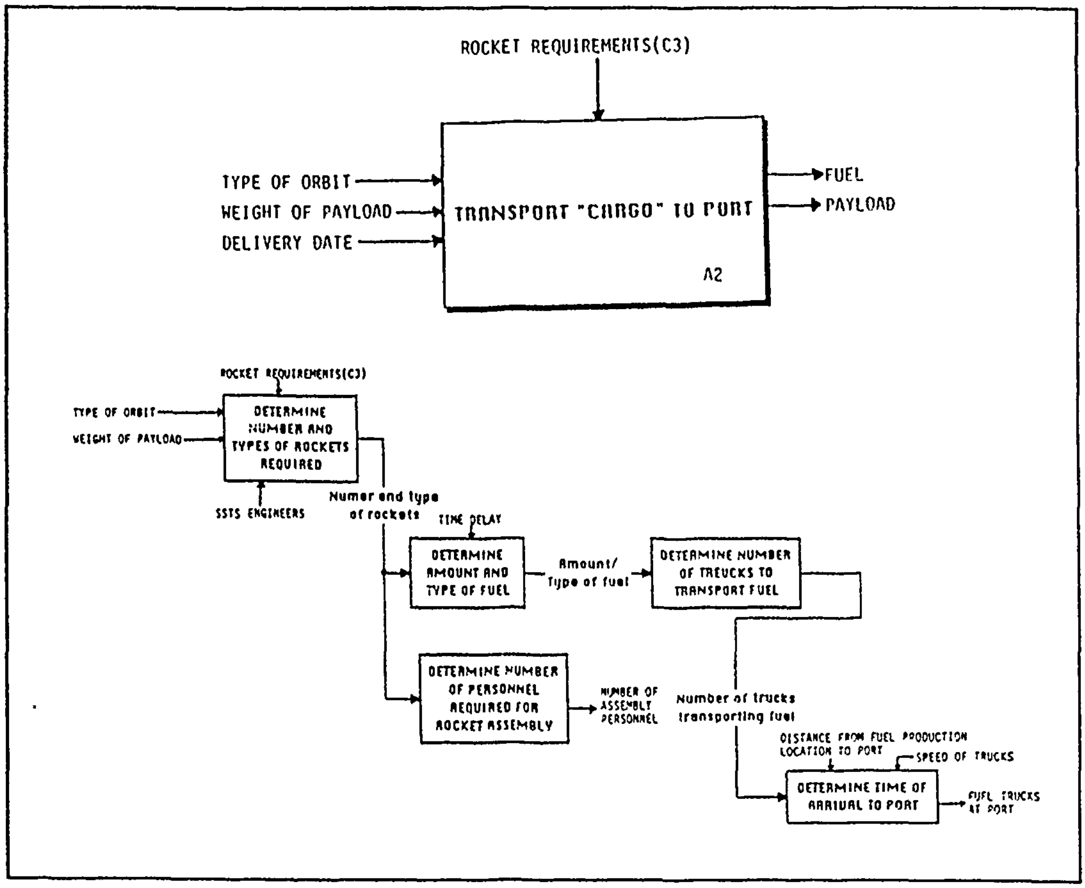

Figure 3: Transport "Cargo" to Port

In order to transport the fuel trucks, assembled rockets, payload and launch personnel to the launch site (A3), a determination must be made as to how many barges will be required (Figure 4). The arrival of the cargo to the marshalling site will be accomplished after the rockets have been assembled. The time of arrival will be based upon the speed of the barges as well as the distance from the port to the marshalling site.

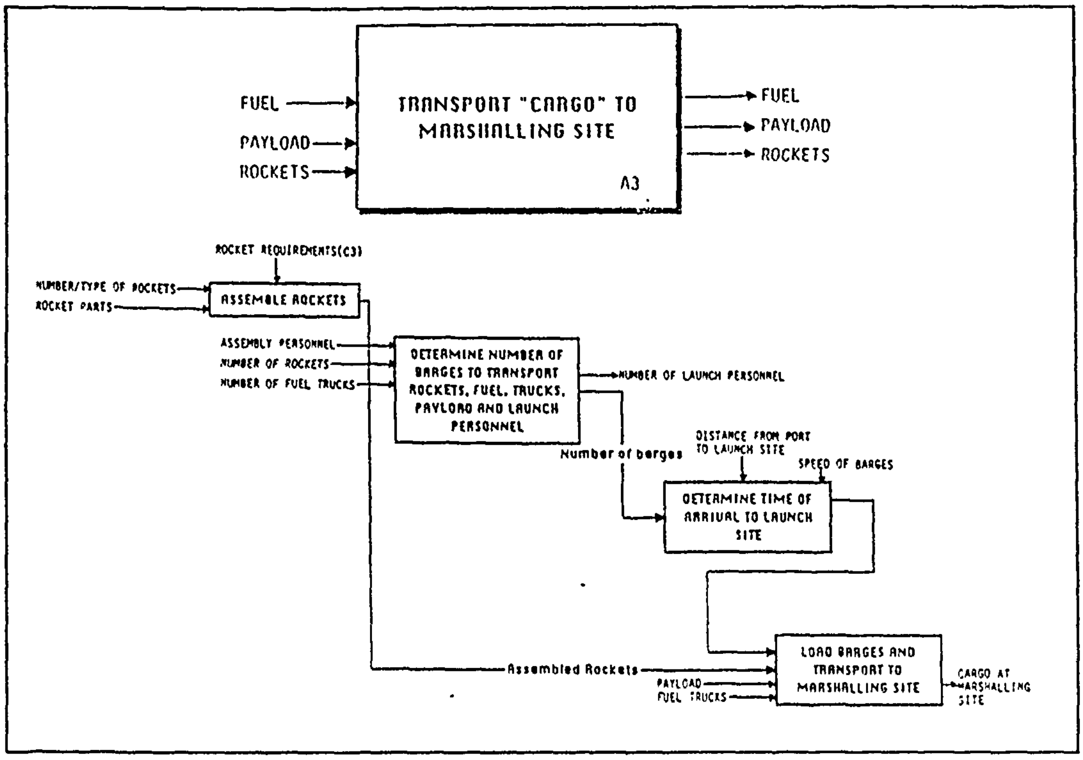

Figure 4: Transport "Cargo" to Marshalling Site (A3)

Once all of the cargo is in place at the marshalling site, the rockets are fueled. The payload/rocket assembly is then towec , the actual launch position and the payload is launched as indicated in Figure 5.

Although the actual mission of launching the payload has been accomplished, since these are recoverable rockets, they must be recovered and returned to port (Figure 6). Once they are returned, they must be refurbished and stored for subsequent launches.

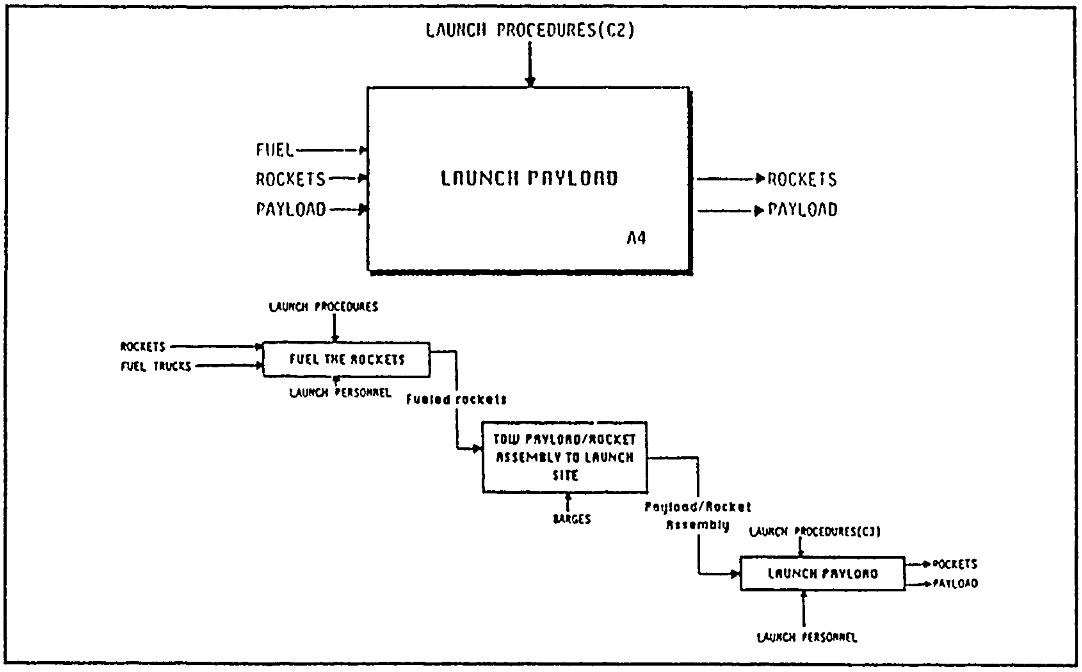

Figure 5: Launch Payload (A4)

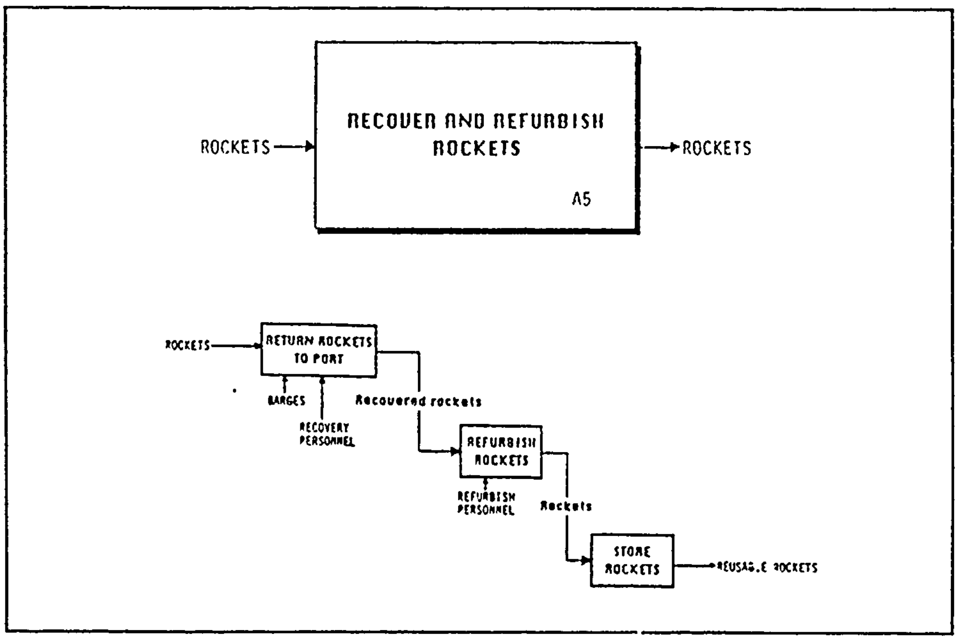

Figure 6: Recover and Refurbish Rockets (A5)

IV. THE MODEL

An optimization model was developed for the Sea Launch and Recovery Transportation System. The objective of the cost estimation model was to minimize the cost per mission performed by the SSTS based on the concept of operations presented in the previous chapter. The model presented here by no means encompasses all of the cost components of the SSTS. This model merely minimizes the costs associated with the fuel tanks of the rocket. It can be used to aid the SSTS designers in making cost effective choices regarding the types of materials to be used in the construction of the fuel tanks. It can also be used in determining the most economical port of operation for the SSTS in terms of these fuel tank costs and the port operating costs.

GAMS (General Algebraic Modeling System) was chosen as the language to be utilized in this problem for several reasons, although this problem could be reduced to a rather simple computation. First, and foremost, GAMS is a high-level language that enables the compact representation of large models and it will be necessary to greatly expand this model to include/examine all of the various components associated with the SSTS. Secondly, although the problem as presented here is linear, it is envisioned that this problem structure may eventually change to include nonlinearities. For example, the research and development costs will most probably involve nonlinearities. GAMS is capable of solving both types of problems. Thirdly, the GAMS model representation is concise and can be easily understood.

A. OVERVIEW

This cost estimation model is used to investigate the economics of operating the Sea Launch and Recovery Space Transportation System from four ports: Honolulu, Hawaii; San Diego, California; Galveston, Texas; and Jacksonville, Florida. The fuels required for the operation of the SEALAR rockets include kerosene (RP-1), liquid oxygen (LOX), liquid hydrogen (LH2), and helium (HEL). In order for these fuels to be carried in the rocket, six fuel tanks are necessary: one RP-1, two LOX (one for each stage), one LH2 , and two HEL (one for each stage). Each of these tanks can be constructed from maraging steel, cryostretched stainless steel, or composites. Additionally, the RP-1, LH2 and HEL tanks can be constructed from titanium.

The Kellogg Company conducted an economic feasibility and optimization study to investigate the economics for producing, purchasing, transporting and storing three of the fuels required for the SSTS. It was based on providing the required quantities of those fuels to initially support twelve launches per year for the next five years (up to 1995) and seventy-two launches thereafter. This model is based on the same premise and makes use of the optimal fuel prices determined by that study. [Ref. 4]

The research and development costs of the tanks are calculated for the development of all of the possible combinations of tanks and materials. These costs are distributed over the total number of missions that the rocket is expected to perform while the cost of the tanks is distributed over the number of rocket reuses. The overhead costs, general expenses associated with the construction of the rocket, are distributed over the number of missions the rocket executes each year.

The model provides reports which can be readily used to determine which port is the most economical in terms of cost per mission and cost per pound of payload based on the input data. A tabular display is also provided indicating the most cost efficient combination of tanks and materials. In addition, the individual costs for each of the major cost components (research and devlopment, operating, refurbishment and overhead) and the cost of the selected fuel tanks are offered in the reports. All of these reports are given based on twelve or seventy-two missions per year.

B. ALGEBRAIC REPRESENTATION

The optimization model of the SEALAR Space Transportaion System problem presented in Appendix A can be represented in algebraic terms as follows.

1. INDICES:

The data used in the model is indexed by fuel types, ports of operation, types of fuel tanks and types of materials used in the construction of fuel tanks. These indices are:

f = types of fuels required for the SEALAR rocket (RP-1, LOX, LH2, HEL)

p = ports of operation of the SSTS (Honolulu, HI; San Diego, CA; Galveston, TX; Jacksonville,FL)

t = types of fuel tanks required for the SEALAR rocket (one RP-1, two LOX, one LH2, two HEL)

m = types of materials used in the construction of fuel tanks (maraging steel, cryostretched stainless st -el, composities, titanium)

2. GIVEN DATA:

The computation of the operating costs, one of the main costs of interest in this model, involved determining the cost of the fuels, the cost of transporting the cargo from the port to the launch site, and the cost of the SSTS personnel.

The data required to compute the cost of the fuels included:

a_f = amount of fuel type f required to launch a 10,000 lb payload (in kgs)

b_f = percent of the total capacity of fuel required to fill the tanks; the tanks are initially at room temperature and must be cooled to the cryogenic temperature of liquids (expressed as a decimal)

td_{fp} = additional fuel f required for "burn-off" while transiting from port p to the launch site (as % of total fuel requirement)

p_{fp} = price of fuel type f at port p (in $/kg) [Ref. 5]

The data necessary in determining the SSTS transportation costs were·

d_p = distance from port p to the launch site (in nautical miles)

s = speed of the transportation (barge, ship) from port to launch site (in miles/hr)

r = barge rental fee per day ($)

$nm1$ = nautical miles to retrieve stage one of the rocket

$nm2$ = nautical miles to retrieve stage two of the rocket

The personnel costs are determined by:

e = number of personnel

es = average annual salary and benefits of the personnel ($)

Minimizing the cost of the SEALAR rocket's fuel tanks was the other important factor in the model. It was necessary to determine the research and

development costs, the unit production costs, the refurbishment costs, and the overhead costs since all of these are components of the total fuel tank costs.

That data which were associated with the research and development costs included:

c_m = cost per pound of material m ($/lb)

dn_{mt} = design cost for tank t constructed from material m ($)

pt_{mt} = prototype and test costs for tank t constructed from material m ($)

pp_{mt} = preproduction cost for tank t constructed from material m ($)

rd_{mt} = amount of material m used in the research and development of tank t constructed of material m (in lbs)

The additional data required to compute the unit production costs are:

fab_{mt} = fabrication cost of tank t constructed from material m ($)

mwt_{mt} = weight of material m used to construct one tank of type t (in lbs)

u = number of reuses of the fuel tanks

int_{mt} = integration testing costs during production of tank t made of material m ($)

The recovery and refurbishment costs are determined by:

rec_{mt} = cost to recover and wash off tank t constructed of material m ($)

i_{mt} = time to inspect tank t constructed of material m (in hrs)

h_{mt} = hourly rate to inspect tank t constructed of material m ($/hr)

rep_{mt} = cost to repair tank t constructed of material m ($)

The overhead costs associated with the fuel tanks are designated as:

ov_{mt} = overhead costs associated with tank t constructed of material m ($)

Other data that are necessary for the computation of the cost per mission and the cost per pound of payload delivered to orbit by the SSTS include:

num = number of Subcalibur rockets

mis = total number of missions

myr = number of missions per year

wt = payload weight (in lbs)

$\mathbf{k_t}$ = number of tanks of type t required per rocket

3. DERIVED DATA

In order to determine the port operating costs, the cost of fuels required for the rockets, the cost of transportation of the mated rockets and recovered stages, and the personnel costs are calculated according to the following equation:

$$\sum_{f}\left[\begin{array}{l}\left(\left\{\left[\mathbf{a}_f+\left(\mathbf{a}_f\times\mathbf{b}_f\right)\right]+\left(\left\{\mathbf{td}_{fp}\times.01\times\left[\mathbf{a}_f+\left(\mathbf{a}_f\times\mathbf{b}_f\right)\right]\right\}\times\frac{\mathbf{wt}}{10000}\right)\right\}\times\mathbf{p}_{fp}\times\mathbf{num}\right)\\+\left(\left\{\left[\left(2\times\left(\mathbf{d}_p+\mathbf{nm1}+\mathbf{nm2}\right)\right)\div\mathbf{s}\right]\div24\right\}\times\mathbf{r}\times\mathbf{num}\right)+\left(\mathbf{e}\times\mathbf{es}\right)\end{array}\right]$$

4. DECISION VARIABLE:

The model will determine the most cost efficient material to use in the construction of the required fuel tanks. This variable is defined as:

$\mathbf{x_{mt}}$ = number of tanks of type t constructed from material m

5. CONSTRAINTS:

The correct number of each type of tank must be constructed:

$$\sum_{m} x_{mt} = k_t \times num$$

Liquid oxygen tanks cannot be constructed from titanium so the following constraint was included in the model:

$$x_{mt} = 0 \text{ for } m\text{=Titanium and } t\text{=LOX}$$

There is also a nonnegativity constraint :

$$x_{mt} \geq 0$$

5. OBJECTIVE FUNCTION:

The objective of the optimization model is to minimize fuel tank costs:

Minimize TANKCOST = costs of tanks including research and development, production, refurbishment and overhead costs

$$= \sum_{m}\sum_{t}\left[\begin{array}{l} \left\{\left[dn_{mt} + pt_{mt} + pp_{mt} + \left(rd_{mt} \times c_m\right)\right] \div mis\right\} \\ + \left\{\left(x_{mt} \times \left[\left(mwt_{mt} \times c_m\right) + fab_{mt} + in_{mt}\right]\right) \div u\right\} \\ + \left\{x_{mt} \times \left[rec_{mt} + \left(i_{mt} \times h_{mt}\right) + rep_{mt}\right]\right\} + \left\{\left(ov_{mt} \times x_{mt}\right) \div myr\right\} \end{array}\right]$$

The solution to this problem can be obtained by finding, for each tank t, the material m which has the lowest variable cost in the preceding equation. That is, for each t, select

$$\min_{m}\left[\begin{array}{l} \left\{\left(\left[\left(mwt_{mt} \times c_m\right) + fab_{mt} + in_{mt}\right]\right) \div u\right\} \\ + \left\{\left[rec_{mt} + \left(i_{mt} \times h_{mt}\right) + rep_{mt}\right]\right\} + \left\{ov_{mt} \div myr\right\} \end{array}\right]$$

This solution can be obtained in closed form but the model has been implemented using an optimization solver to accomodate future extension.

V. ANALYSIS

The Sea Launch and Recovery Transportation System is in the development phase and, thus, there are no observed values with which to analyze the model presented in Chapter IV. It was therefore necessary to use estimates in analyzing the model and determining the relationships that exist between the variables. These estimates will be varied in the different scenarios to conduct sensitivity analysis.

A. SCENARIO NUMBER ONE

The estimates used in the optimization model of Appendix A generated the reports in Appendix B. Tables 2 and 3 summarize these reports. These tables present the operating costs for San Diego, California since it was determined to be the most economical port of operation.

TABLE 2

SSTS PER MISSION COSTS

(BASED ON 12 MISSIONS PER YEAR)

Number of Rocket Reuses	1	2	5	10	25
Research and Development	755,000	755,000	755,000	755,000	755,000
Tank Costs	4,945,000	2,473,000	989,000	495,000	198,000
Operating Costs	2,746,000	2,746,000	2,746,000	2,746,000	2,746,000
Refurbishment Costs	66,000	66,000	66,000	66,000	66,000
Overhead Costs	6,000	6,000	6,000	6,000	6,000
Cost Per Mission	8,518,000	6,045,000	4,561,000	4,067,000	3,770,000

TABLE 3

SSTS PER MISSION COSTS

(BASED ON 72 MISSIONS PER YEAR)

Number of Rocket Reuses	1	2	5	10	25
Research and Development	755,000	755,000	755,000	755,000	755,000
Tank Costs	4,945,000	2,473,000	989,000	495,000	198,000
Operating Costs	2,717,000	2,717,000	2,717,000	2,717,000	2,717,000
Refurbishment Costs	66,000	66,000	66,000	66,000	66,000
Overhead Costs	972	972	972	972	972
Cost Per Mission	8,484,000	6,011,000	4,528,000	4,033,000	3,736,000

In this base case, maraging steel was selected by the optimization program as the material from which all of the fuel tanks would be constructed regardless of the number of missions per year or the number of rocket reuses as shown in Table 4. The cost of these rocket fuel tanks accounts for the differences in the cost per mission as all other costs except the operating costs remain constant regardless of the number of missions per year or the number of reuses of the rocket as the tables indicate. The operating costs do, however, remain constant as the number of rocket reuses change because they are based on the number of rockets used in the mission. The constancy in the research and development costs is due to the fact that those costs are based on developing fuel tanks for all possible fuel-tank material combinations. Since the refurbishment and overhead costs are dependent upon the fuel-tank material combinations selected by the model and these combinations remained the same for all missions, these costs remain constant.

TABLE 4

TANK COMBINATIONS SELECTED BASED ON THE NUMBER OF ROCKET REUSES AND 12 OR 72 MISSIONS PER YEAR

TYPE OF FUEL TANK	1	2	5	10	25
KEROSENE	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL
LIQUID OXYGEN (STAGE 1)	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL
LIQUID OXYGEN (STAGE 2)	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL
LIQUID HYDROGEN	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL
HELIUM (STAGE 1)	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL
HELIUM (STAGE 2)	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL

The cost of the fuel tanks and thus the cost per mission decreases significantly as the number of reuses of the rocket increases. There is, in fact, a reduction of $4,748,000 when the fuel tanks are used twenty-five times instead of only once.

As expected, operating costs decreased as the number of missions per year increased (an approximate savings of $29,000). This is due to the fact that the fuel costs for liquid oxygen and liquid hydrogen decreased due to price breaks for bulk buying as the number of missions increased from twelve to seventy-two [Ref. 4]. Also, there is an inverse relationship between the number of missions per year and overhead costs. The overhead costs for 72 missions were one-sixth those for twelve missions. These reductions in operating and overhead costs resulted in a $34,000 per mission savings when conducting 72 missions rather than 12 missions per year.

However, regardless of the number of missions performed each year, the differences in per mission costs remain constant as the number of reuses increases.

B. SCENARIO NUMBER TWO

Since maraging steel was selected exclusively as the material for the fuel tanks in the first scenario, the cost per pound of maraging steel was increased to $30,000 (one hundred times its original cost) to verify that the model would select the most cost efficient combination of materials and fuel tanks. This price increase varied the selection of fuel-tank material combinations. The combinations of fuel tanks and materials that were selected are shown in Tables 5 and 6. It should be noted that in this scenario, the materials change as the number of reuses change but not with the change in the number of missions.per year.

TABLE 5

TANK COMBINATIONS SELECTED WHEN COST OF MARAGING STEEL IS INCREASED SIGNIFICANTLY BASED 12 MISSIONS PER YEAR

TYPE OF FUEL TANK	1	2	5	10	25
KEROSENE	TITANIUM	TITANIUM	TITANIUM	TITANIUM	CRYOSTRETCH STEEL
LIQUID OXYGEN (STAGE 1)	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL
LIQUID OXYGEN (STAGE 2)	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL
LIQUID HYDROGEN	TITANIUM	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL
HELIUM (STAGE 1)	TITANIUM	TITANIUM	TITANIUM	TITANIUM	TITANIUM
HELIUM (STAGE 2)	TITANIUM	TITANIUM	TITANIUM	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL

TABLE 6

TANK COMBINATIONS SELECTED BASED ON THE NUMBER OF ROCKET REUSES AND 72 MISSIONS PER YEAR

TYPE OF FUEL TANK	1	2	5	10	25
KEROSENE	TITANIUM	TITANIUM	TITANIUM	TITANIUM	CRYOSTRETCHED STEEL
LIQUID OXYGEN (STAGE 1)	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL
LIQUID OXYGEN (STAGE 2)	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL
LIQUID HYDROGEN	TITANIUM	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL
HELIUM (STAGE 1)	TITANIUM	TITANIUM	TITANIUM	TITANIUM	TITANIUM
HELIUM (STAGE 2)	TITANIUM	TITANIUM	TITANIUM	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL

As indicated in the reports for the second scenario found in Appendix C, tank, refurbishment, and overhead costs are dependent upon the type of material chosen for the tanks. Therefore, these costs vary if the type of tank material varies. A summary of the costs for this scenario for 12 missions, Table 7, indicates the operating costs and most economical port of operation were not affected by these choices. The costs for 72 missions per year were identical to those for twelve except for the reduction in operating and overhead costs. This verifies the results shown in the base case scenario (Scenario Number One).

TABLE 7

SSTS PER MISSION COSTS

(BASED ON 12 MISSIONS PER YEAR WHEN THE COST OF

MARAGING STEEL IS INCREASED SIGNIFICANTLY)

Number of Rocket Reuses	1	2	5	10	25
Research and Development	11,748,000	11,748,000	11,748,000	11,748,000	11,748,000
Tank Costs	6,737,000	3,375,000	1,350,000	676,000	273,000
Operating Costs	2,746,000	2,746,000	2,746,000	2,746,000	2,746,000
Refurbishment Costs	83,000	72,000	72,000	71,000	66,000
Overhead Costs	2,667	2,667	2,667	2,792	2,792
Cost Per Mission	21,316,667	17,943,667	15,918,667	15,243,792	14,835,792

C. SCENARIO NUMBER THREE

As a third scenario, the cost of composites were decreased to $200 per pound while the cost of maraging steel remained at $30,000 per pound. The reports generated by this scenario are in Appendix D. Table 8 displays the choices made for the fuel-tank material combinations. As in the previous case, the choices remained the same regardless of the number of missions per year. This scenario further verified that the most economical combination of fuel tanks and materials would be chosen by the model and that San Diego is the most economical port of operation.

TABLE 8

TANK COMBINATIONS SELECTED BASED ON THE NUMBER OF ROCKET REUSES

TYPE OF FUEL TANK	1	2	5	10	25
KEROSENE	TITANIUM	TITANIUM	TITANIUM	TITANIUM	CRYOSTRETCHED STEEL
LIQUID OXYGEN (STAGE 1)	COMPOSITES	COMPOSITES	COMPOSITES	COMPOSITES	COMPOSITES
LIQUID OXYGEN (STAGE 2)	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL
LIQUID HYDROGEN	TITANIUM	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL
HELIUM (STAGE 1)	COMPOSITES	COMPOSITES	COMPOSITES	COMPOSITES	COMPOSITES
HELIUM (STAGE 2)	COMPOSITES	COMPOSITES	COMPOSITES	COMPOSITES	CRYOSTRETCH STAINLESS STEEL

D. SCENARIO NUMBER FOUR

The research and development costs in all of the previous scenarios were based on developing all of the possible fuel-tank material combinations. In trying to further reduce the cost per mission, a variation of the model was implemented in which research and development costs would be calculated for only those fuel tank-material combinations selected by the model. This variation involved changing the objective function of the model to include the decision variable in the calculation of the research and development costs. The new objective function is:

Minimize TANKCOST

$$
= \sum_m \sum_t \left[\begin{array}{l} \left\{\left(\left[dn_{mt} + pt_{mt} + pp_{mt} + \left(rd_{mt} \times c_m\right)\right] \times x_{mt}\right) \div mis\right\} \\ + \left\{\left(x_{mt} \times \left[\left(mwt_{mt} \times c_m\right) + fab_{mt} + in_{mt}\right]\right) \div u\right\} \\ + \left\{x_{mt} \times \left[rec_{mt} + \left(i_{mt} \times h_{mt}\right) + rep_{mt}\right]\right\} + \left\{\left(ov_{mt} \times x_{mt}\right) \div myr\right\} \end{array} \right]
$$

The reports generated using this objective function for the three scenarios are contained in Appendix E. It was found that the research and development costs were significantly reduced but that all other costs remained the same. The savings for the three different scenarios is shown in Table 9. Once again, it is evident that the savings is dependent upon the type of material chosen for the rocket fuel tanks.

TABLE 9

SAVINGS FROM CALCULATING RESEARCH AND DEVELOPMENT COSTS FOR SPECIFIED TANKS ONLY

SCENARIO	SAVINGS
NUMBER ONE	755,000 - 130,000 = 625,000
NUMBER TWO	11,748,000 - 178,000 = 11,570,000
NUMBER THREE	11,449,000 - 86,000 = 11,363,000

The possible variations in this model are endless considering that only estimates are being utilized in the analysis. It has been verified, however, that the operating costs of the Sea Launch and Recovery Space Transportation System can be reduced significantly if the number of reuses of the rocket can be increased. Furthermore,

the cost of the rocket fuel tanks is dependent upon the variation of the materials used in their construction but can be reduced significantly if research and development is conducted only for the most cost efficient tanks selected for the mission.

VI. CONCLUSIONS

This study indicates that it is possible to develop a cost estimation model for the rocket fuel tanks and operating costs associated with the Sea Launch and Recovery Space Transportation System. The cost of the material used in the fuel tanks can have a significant effect on the cost per mission of the SSTS. A signicant decrease in costs can also be achieved by developing only those fuel-tank material combinations selected by the model.

It is recommended that as actual data becomes available, additional studies be conducted in order to verify and correct, as necessary, those assumptions and simplifications used in this model. In addition, this model should eventually be expanded to include every possible component of the SSTS. It is only through the development of such a model that the true economic value of the SSTS can be determined.

LIST OF REFERENCES

1. Truax Engineering, Inc., "Proposal for SEALAR Program", 1988.

2. Truax, R. C., "Sea Dragon in the Manned Mars Mission", paper, 1987.

3. *Aerojet General Report LRP 297*, February 1963.

4. Naval Research Laboratory, Memorandum Report 3086, "Structured Analysis Model for Naval Telecommunications Procedures User's Manual NTP3", July 1975.

5. M. W. Kellogg Company, "Cyrogenics Study", paper presented to the Naval Research Laboratory, 1990.

APPENDIX A

SEALAR SPACE TRANSPORTATION SYSTEM MODEL

```
OPTION LIMROW=0, LIMCOL=0 ;


* By: LAYNE R. BOONE (7 AUG 90)


*********************************************************************
*     THIS IS THE BEGINNING OF THE INPUT DATA FOR THE SSTS
*********************************************************************


SETS
      F  fuel types        / KEROSENE, OXYGEN, HYDROGEN, HELIUM /
      P  ports             / HONOLULU, SANDIEGO, GALVESTON, JACKSONVIL/
      M  types of tank materials / MARAGING, CRYOSTRCH, COMPOSITES,
                                   TITANIUM /
      T tank types         / RP1, LOX1, LOX2, LH2, HEL1, HEL2/ ;

SCALARS  NUM      number of Subcalibur rockets / 1 /
         NUMMIS   total number of missions  / 100 /
         MISYR    missions per year  / 12 /
         WT       payload weight   / 10000 / ;

PARAMETER AMT(F)  amount of fuel type f required for 10000 lb payload

                  / KEROSENE     1079
                    OXYGEN     150152
                    HYDROGEN     9815
                    HELIUM        591 / ;

PARAMETER BOFF(F) boil-off allowances for fuel type f

                 / KEROSENE   0.0
                   OXYGEN      .30
                   HYDROGEN   1.00
                   HELIUM     2.80 / ;

TABLE  TDREQ(F,P)  additional fluid requirements for time delay

                   HONOLULU  SANDIEGO  GALVESTON   JACKSONVIL
        KEROSENE     0.0       0.0       0.0          0.0
        OXYGEN       3.0       4.5       9.0          6.75
        HYDROGEN     2.0       3.0       6.0          4.5
        HELIUM       6.0       9.0      18.0         12.0      ;

TABLE  PRICE(F,P)  best price per kg of fuel f at port p

                   HONOLULU  SANDIEGO  GALVESTON   JACKSONVIL
        KEROSENE     0.14      0.14      0.14         0.14
        OXYGEN       0.51      0.18      0.18         0.18
        HYDROGEN    11.11      5.93      4.52         4.74
        HELIUM      22.03     10.13      9.91        10.26    ;


PARAMETER DIST(P)  distance from port p to launch site in miles

```

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                      / HONOLULU     1560
                        SANDIEGO     2380
                        GALVESTON    4630
                        JACKSONVIL   3690 /  ;


SCALAR BSPEED  average barge speed  / 17 / ;

SCALAR BRENT  barge rental fee per day / 5000 / ;

SCALAR NMTO1 miles to retrieve first stage / 200 / ;

SCALAR NMTO2 miles to retrieve second stage / 50 / ;

SCALAR PERS number of personnel / 50 / ;

SCALAR SALARY average annual salary / 50000 / ;

PARAMETER TANK(T) number of tanks of type t required per rocket

                     / RP1       1
                       LOX1      1
                       LOX2      1
                       LH2       1
                       HEL1      1
                       HEL2      1 / ;

PARAMETER MCOST(M) cost per pound of material type m

                      / MARAGING        300
                        CRYOSTRCH       500
                        COMPOSITES     3000
                        TITANIUM        700 / ;

TABLE FABRICATE(M,T) fabrication cost of tank t of material m

                           RP1      LOX1      LOX2      LH2      HEL1     HEL2
      MARAGING           100000    300000    250000    400000   50000    40000
      CRYOSTRCH          100000    400000    350000    500000   60000    50000
      COMPOSITES        1000000   1200000   1100000   1000000  100000    90000
      TITANIUM           110000       0         0      500000   60000    50000 ;

TABLE DESIGN(M,T) design cost for tank t of material type m

                           RP1      LOX1      LOX2      LH2      HEL1     HEL2
      MARAGING            50000     70000     70000    120000   40000    70000
      CRYOSTRCH           50000     70000     70000    120000   40000    70000
      COMPOSITES         100000    140000    140000    240000   80000    60000
      TITANIUM            50000       0         0      100000   40000    30000 ;

TABLE TEST(M,T) prototype and test cost for tank of material type m

                           RP1      LOX1      LOX2      LH2      HEL1     HEL2
      MARAGING           200000    220000    200000    250000   50000    40000
      CRYOSTRCH          300000    250000    250000    300000   50000    50000
      COMPOSITES         600000    700000    700000    850000   60000    50000
```

```
        TITANIUM        300000      0          0          450000    50000     40000 ;

TABLE PREPRO(M,T) preproduction cost for tank t of material type m

                         RP1        LOX1       LOX2       LH2       HEL1      HEL2
        MARAGING        100000     100000     100000     150000    40000     30000
        CRYOSTRCH       100000     125000     125000     175000    50000     40000
        COMPOSITES      250000     200000     200000     300000    60000     50000
        TITANIUM        150000      0          0          250000    40000     30000 ;

TABLE RDAMT(M,T) amount of material type m used in r and d of tank t

                         RP1        LOX1       LOX2       LH2       HEL1      HEL2
        MARAGING         7134       17343      1953       2676      7221      687
        CRYOSTRCH        6141       14928      1680       2304      6216      591
        COMPOSITES       1986        4830       543        744      2010      192
        TITANIUM         4065         0          0        1524      4113      390  ;

TABLE MWT(M,T) weight of material type m used in one tank

                         RP1        LOX1       LOX2       LH2       HEL1      HEL2
        MARAGING         2378       5781       651        892       2407      229
        CRYOSTRCH        2047       4976       560        768       2072      197
        COMPOSITES        662       1610       181        248        670       64
        TITANIUM         1355        0          0         508       1371      130  ;

TABLE RECOVERY(M,T) recovery and wash off cost for type m of tank t

                         RP1        LOX1       LOX2       LH2       HEL1      HEL2
        MARAGING         10000      12000      12000      20000     2000      2000
        CRYOSTRCH        10000      12000      12000      20000     2000      2000
        COMPOSITES       20000      24000      24000      40000     4000      4000
        TITANIUM         15000        0          0        30000     3000      3000 ;

TABLE INSPECT(M,T) inspection time for tank t of material type m

                         RP1        LOX1       LOX2       LH2       HEL1      HEL2
        MARAGING          5          8          8          12        1         1
        CRYOSTRCH         1          2          2          3          .5        .5
        COMPOSITES        6          9          9          15        2         2
        TITANIUM          1          0          0          3          .5        .5 ;

PARAMETER RATE(M) rate per hour for inspection of type m material

           / MARAGING          60
             CRYOSTRCH         70
             COMPOSITES       200
             TITANIUM          60  / ;

TABLE REPAIR(M,T) repair cost for tank t of material type m

                         RP1        LOX1       LOX2       LH2       HEL1      HEL2
        MARAGING         1000       1200       1200       2000      200       200
        CRYOSTRCH        1000       1200       1200       2000      200       200
        COMPOSITES       2000       2400       2400       4000      400       400
        TITANIUM         1500        0          0         3000      300       300  ;
```

```

SCALAR REUSE number of reuses of tanks / 1 / ;

TABLE UTEST(M,T) unit test cost for tank t of material type m

                           RP1      LOX1     LOX2     LH2     HEL1     HEL2
      MARAGING            20000    20000    20000    30000    8000     6000
      CRYOSTRCH           20000    25000    25000    35000   10000     8000
      COMPOSITES          50000    40000    40000    60000   12000    10000
      TITANIUM            30000        0        0    50000    8000     6000 ;

TABLE OVHEAD(M,T) overhead cost for tank t of material type m

                           RP1      LOX1     LOX2     LH2     HEL1     HEL2
      MARAGING            20000    10000    10000    20000    5000     5000
      CRYOSTRCH           10000     5000     5000    10000    2500     2500
      COMPOSITES          60000    30000    30000    60000   15000    15000
      TITANIUM            10000        0        0    10000    1000     1000 ;


***********************************************************************
*     THIS IS THE BEGINNING OF THE CALCULATIONS REQUIRED TO COMPUTE
*     THE COST PER MISSION FOR THE PORT OPERATIONS AND THE ROCKET
*     FUEL TANKS
***********************************************************************


PARAMETERS
    ADD(F)          additional fuel required to account for boiloff
    NEWAMT(F)       required fuel plus additional fuel
    FREQ(F,P)       total amount of fuel required for payload of weight wt
    FUELCOST(P)     cost of fuel for payload of weight wt
    TRANSCOST(P)    cost of transportation
    PERSCOST        personnel costs
    OPCOST(P)       total operating costs at port p
    RDCOST(M,T)     research and development cost for tank t of material m
    RD              research and development cost per mission for tanks
    UNITCOST(M,T)   unit production cost for tank t of material m
    REFURB(M,T)     refurbishment cost for tank t of material m  ;

***********************************************************************
*     THESE ARE THE CALCULATIONS FOR THE OPERATING COSTS
***********************************************************************


ADD(F) = AMT(F) * BOFF(F) ;

NEWAMT(F) = ADD(F) + AMT(F)  ;

FREQ(F,P) = (NEWAMT(F) + (TDREQ(F,P) * .01 * NEWAMT(F))) * (WT/10000) ;

FUELCOST(P) = SUM(F, FREQ(F,P) * PRICE(F,P)) * NUM;

TRANSCOST(P) =
          (((2 * (DIST(P) + NMTO1 + NMTO2))/BSPEED)/24) * BRENT * NUM ;

```

```
PERSCOST = PERS * SALARY ;

OPCOST(P) =  (FUELCOST(P) + TRANSCOST(P) + PERSCOST) ;


***************************************************************************
*     THESE CALCULATIONS ARE REQUIRED FOR THE FUEL TANK COSTS
***************************************************************************

RDCOST(M,T) = DESIGN(M,T)+TEST(M,T)+PREPRO(M,T)+(RDAMT(M,T)*MCOST(M)) ;

RD = (SUM((M,T), RDCOST(M,T))/NUMMIS);

UNITCOST(M,T) = ((MWT(M,T) * MCOST(M)) + FABRICATE(M,T) + UTEST(M,T) ;

REFURB(M,T) = (RECOVERY(M,T) + (INSPECT(M,T)*RATE(M)) + REPAIR(M,T)) ;

VARIABLES
   X(M,T)        number of tanks type t of material m
   TANKS         cost of tanks for this mission
   REF           total recovery and refurbishment costs for this mission
   OVH           total overhead costs for tanks per mission per year
   TOTCOST       total cost of tanks ;

POSITIVE VARIABLES X, TANKS, REF, OVH;

EQUATIONS
  REQTANKS(T)   number of tanks of type t required for the mission
  TCOST         cost of tanks for this mission
  REFURBISH     total recovery and refurbishment costs for this mission
  OVERHEAD      total overhead costs for tanks per mission per year
  TANKCOST      total cost of tanks ;


***************************************************************************
*     THESE CALCULATIONS ARE ALSO REQUIRED FOR THE FUEL TANK COSTS
***************************************************************************


 REQTANKS(T)..     SUM(M, X(M,T)) =E= (TANK(T) * NUM) ;

 TCOST..           TANKS =E=
                        SUM((M,T), (X(M,T) * UNITCOST(M,T))/REUSE);

 REFURBISH..       REF =E= SUM((M,T), X(M,T) * REFURB(M,T)) ;

 OVERHEAD..        OVH =E= (SUM((M,T), (OVHEAD(M,T)*X(M,T)))/MISYR) ;


***************************************************************************
*     THIS CALCULATION IS REQUIRED FOR PORT COST PER MISSION
***************************************************************************


TANKCOST..    TOTCOST =E= RD + TANKS + REF + OVH ;
```

```
MODEL SSTS /ALL/ ;


************************************************************************
*      THIS IS WHERE THE FORMATING FOR THE REPORTS BEGINS.
*      THE REPORTS ARE FORMULATED SO ONE CAN EASILY DETERMINE WHICH
*      PORT IS MOST ECONOMICAL AND WHICH TYPE TANKS ARE MOST COST
*      EFFICIENT.
************************************************************************


PARAMETER REPORT1(*,*)  port costs per mission for 12 missions per year ;
PARAMETER REPORT7(*,*)  port costs per lb for twelve missions per year ;
PARAMETER REPORT2(*,*,*)  number of tanks for 12 missions per year ;
PARAMETER REPORT3(*,*)  port costs per mission for 72 missions per year ;
PARAMETER REPORT8(*,*)  port costs per lb for 72 missions per year ;
PARAMETER REPORT4(*,*,*)  number of tanks for 72 missions per year ;
PARAMETER REPORT5(*) research and development costs per mission ;
PARAMETER REPORT6(*) research and development costs per mission ;
PARAMETER REPORT9(*)  refurbishment costs per mission ;
PARAMETER REPORT11(*)  refurbishment costs per mission ;
PARAMETER REPORT10(*)  overhead costs per mission ;
PARAMETER REPORT12(*)  overhead costs per mission ;
PARAMETER REPORT13(*)  tank costs per mission ;
PARAMETER REPORT14(*)  tank costs per mission ;
PARAMETER REPORT15(*,*)  operating costs at port p for this mission ;
PARAMETER REPORT16(*,*)  operating costs at port p for this mission ;


************************************************************************
*      THE FOLLOWING TWO LINES ENSURE THAT TITANIUM IS NOT USED
*      FOR THE LOX1 OR LOX2 TANKS (THIS IS A RESTRICTION)
************************************************************************


X.FX("TITANIUM","LOX1") = 0;
X.FX("TITANIUM","LOX2") = 0 ;


************************************************************************
*      THE REPORTS FOR 12 MISSIONS PER YEAR BEGIN HERE
*      THE NUMBER OF ROCKET REUSES ARE 1, 2, 5, 10, AND 25
************************************************************************


REUSE = 1;
SOLVE SSTS USING LP MINIMIZING TOTCOST     ;
REPORT5('one reuse') = RD;
REPORT2(M,T,'one') = X.L(M,T);
REPORT13('one reuse') = TANKS.L;
REPORT15(P,'one reuse') = OPCOST(P);
REPORT9('one reuse') = REF.L;
REPORT10('one reuse') = OVH.L;
REPORT1(P,'one reuse') = OPCOST(P) + TOTCOST.L ;
REPORT7(P,'one reuse') = (OPCOST(P) + TOTCOST.L)/WT;
```

```
REUSE = 2;
SOLVE SSTS USING LP MINIMIZING TOTCOST    ;
REPORT5('two reuses') = RD;
REPORT2(M,T,'two reuses') = X.L(M,T);
REPORT13('two reuses') = TANKS.L;
REPORT15(P,'two reuses') = OPCOST(P);
REPORT9('two reuses') = REF.L;
REPORT10('two reuses') = OVH.L;
REPORT1(P,'two reuses') = OPCOST(P) + TOTCOST.L ;
REPORT7(P,'two reuses') = (OPCOST(P) + TOTCOST.L)/WT;

REUSE = 5;
SOLVE SSTS USING LP MINIMIZING TOTCOST    ;
REPORT5('five reuse') = RD;
REPORT2(M,T,'five reuse') = X.L(M,T);
REPORT13('five reuse') = TANKS.L;
REPORT15(P,'five reuse') = OPCOST(P);
REPORT9('five reuse') = REF.L;
REPORT10('five reuse') = OVH.L;
REPORT1(P,'five reuse') = OPCOST(P) + TOTCOST.L ;
REPORT7(P,'five reuse') = (OPCOST(P) + TOTCOST.L)/WT;

REUSE = 10;
SOLVE SSTS USING LP MINIMIZING TOTCOST    ;
REPORT5('ten reuses') = RD;
REPORT2(M,T,'ten reuses') = X.L(M,T);
REPORT13('ten reuses') = TANKS.L;
REPORT15(P,'ten reuses') = OPCOST(P);
REPORT9('ten reuses') = REF.L;
REPORT10('ten reuses') = OVH.L;
REPORT1(P,'ten reuses') = OPCOST(P) + TOTCOST.L ;
REPORT7(P,'ten reuses') = (OPCOST(P) + TOTCOST.L)/WT;

REUSE = 25;
SOLVE SSTS USING LP MINIMIZING TOTCOST    ;
REPORT5('25 reuses') = RD;
REPORT2(M,T,'25 reuses') = X.L(M,T);
REPORT13('25 reuses') = TANKS.L;
REPORT15(P,'25 reuses') = OPCOST(P);
REPORT9('25 reuses') = REF.L;
REPORT10('25 reuses') = OVH.L;
REPORT1(P,'25 reuses') = OPCOST(P) + TOTCOST.L ;
REPORT7(P,'25 reuse') = (OPCOST(P) + TOTCOST.L)/WT;


***************************************************************************
*     THE REPORTS FOR 72 MISSIONS PER YEAR BEGIN HERE
*     THE FUEL PRICES CHANGE FOR OXYGEN AND HYDROGEN
*     THE NUMBER OF ROCKET REUSES ARE 1, 2, 5, 10, AND 25
***************************************************************************


PRICE("OXYGEN","HONOLULU")=0.31;
PRICE("OXYGEN","SANDIEGO")=0.13;
PRICE("OXYGEN","GALVESTON")=0.13;
PRICE("OXYGEN","JACKSONVIL")=0.13;
```

```
PRICE("HYDROGEN","HONOLULU")=6.59;
PRICE("HYDROGEN","SANDIEGO")=5.00;
PRICE("HYDROGEN","GALVESTON")=3.88;
PRICE("HYDROGEN","JACKSONVIL")=4.10;
MISYR = 72 ;
REUSE = 1;
SOLVE SSTS USING LP MINIMIZING TOTCOST    ;
REPORT6('one reuse') = RD;
REPORT4(M,T,'one') = X.L(M,T);
REPORT14('one reuse') = TANKS.L;
REPORT16(P,'one reuse') = OPCOST(P);
REPORT11('one reuse') = REF.L;
REPORT12('one reuse') = OVH.L;
REPORT3(P,'one reuse') = OPCOST(P) + TOTCOST.L ;
REPORT8(P,'one reuse') = (OPCOST(P) + TOTCOST.L)/MT;

PRICE("OXYGEN","HONOLULU")=0.31;
PRICE("OXYGEN","SANDIEGO")=0.13;
PRICE("OXYGEN","GALVESTON")=0.13;
PRICE("OXYGEN","JACKSONVIL")=0.13;
PRICE("HYDROGEN","HONOLULU")=6.59;
PRICE("HYDROGEN","SANDIEGO")=5.00;
PRICE("HYDROGEN","GALVESTON")=3.88;
PRICE("HYDROGEN","JACKSONVIL")=4.10;
MISYR = 72 ;
REUSE = 2;
SOLVE SSTS USING LP MINIMIZING TOTCOST    ;
REPORT6('two reuses') = RD;
REPORT4(M,T,'two reuses') = X.L(M,T);
REPORT14('two reuses') = TANKS.L;
REPORT16(P,'two reuses') = OPCOST(P);
REPORT11('two reuses') = REF.L;
REPORT12('two reuses') = OVH.L;
REPORT3(P,'two reuses') = OPCOST(P) + TOTCOST.L ;
REPORT8(P,'two reuses') = (OPCOST(P) + TOTCOST.L)/MT;

PRICE("OXYGEN","HONOLULU")=0.31;
PRICE("OXYGEN","SANDIEGO")=0.13;
PRICE("OXYGEN","GALVESTON")=0.13;
PRICE("OXYGEN","JACKSONVIL")=0.13;
PRICE("HYDROGEN","HONOLULU")=6.59;
PRICE("HYDROGEN","SANDIEGO")=5.00;
PRICE("HYDROGEN","GALVESTON")=3.88;
PRICE("HYDROGEN","JACKSONVIL")=4.10;
MISYR = 72 ;
REUSE = 5;
SOLVE SSTS USING LP MINIMIZING TOTCOST    ;
REPORT6('five reuse') = RD;
REPORT4(M,T,'five reuse') = X.L(M,T);
REPORT14('five reuse') = TANKS.L;
REPORT16(P,'five reuse') = OPCOST(P);
REPORT11('five reuse') = REF.L;
REPORT12('five reuse') = OVH.L;
REPORT3(P,'five reuse') = OPCOST(P) + TOTCOST.L ;
REPORT8(P,'five reuse') = (OPCOST(P) + TOTCOST.L)/MT;
```

```
PRICE("OXYGEN","HONOLULU")=0.31;
PRICE("OXYGEN","SANDIEGO")=0.13;
PRICE("OXYGEN","GALVESTON")=0.13;
PRICE("OXYGEN","JACKSONVIL")=0.13;
PRICE("HYDROGEN","HONOLULU")=6.59;
PRICE("HYDROGEN","SANDIEGO")=5.00;
PRICE("HYDROGEN","GALVESTON")=3.88;
PRICE("HYDROGEN","JACKSONVIL")=4.10;
MISYR = 72 ;
REUSE = 10;
SOLVE SSTS USING LP MINIMIZING TOTCOST    ;
REPORT6('ten reuses') = RD;
REPORT4(M,T,'ten reuses') = X.L(M,T);
REPORT14('ten reuses') = TANKS.L;
REPORT16(P,'ten reuses') = OPCOST(P);
REPORT11('ten reuses') = REF.L;
REPORT12('ten reuses') = OVH.L;
REPORT3(P,'ten reuses') = OPCOST(P) + TOTCOST.L ;
REPORT8(P,'ten reuses') = (OPCOST(P) + TOTCOST.L)/WT;

PRICE("OXYGEN","HONOLULU")=0.31;
PRICE("OXYGEN","SANDIEGO")=0.13;
PRICE("OXYGEN","GALVESTON")=0.13;
PRICE("OXYGEN","JACKSONVIL")=0.13;
PRICE("HYDROGEN","HONOLULU")=6.59;
PRICE("HYDROGEN","SANDIEGO")=5.00;
PRICE("HYDROGEN","GALVESTON")=3.88;
PRICE("HYDROGEN","JACKSONVIL")=4.10;
MISYR = 72 ;
REUSE = 25;
SOLVE SSTS USING LP MINIMIZING TOTCOST    ;
REPORT6('25 reuses') = RD;
REPORT4(M,T,'25 reuses') = X.L(M,T);
REPORT14('25 reuses') = TANKS.L;
REPORT16(P,'25 reuses') = OPCOST(P);
REPORT11('25 reuses') = REF.L;
REPORT12('25 reuses') = OVH.L;
REPORT3(P,'25 reuses') = OPCOST(P) + TOTCOST.L ;
REPORT8(P,'25 reuse') = (OPCOST(P) + TOTCOST.L)/WT;


OPTION DECIMALS=0 ;
DISPLAY REPORT5, REPORT2, REPORT13, REPORT15, REPORT9, REPORT10, REPORT1,
  REPORT7;
DISPLAY REPORT6, REPORT4, REPORT14, REPORT16, REPORT11, REPORT12,
 REPORT3, REPORT8;
```

SEALAR SPACE TRANSPORTATION SYSTEM MODEL

SETS

F	FUEL TYPES
M	TYPES OF TANK MATERIALS
P	PORTS
T	TANK TYPES

PARAMETERS

ADD	ADDITIONAL FUEL REQUIRED TO ACCOUNT FOR BOILOFF
AMT	AMOUNT OF FUEL TYPE F REQUIRED FOR 10000 LB PAYLOAD
BOFF	BOIL-OFF ALLOWANCES FOR FUEL TYPE F
BRENT	BARGE RENTAL FEE PER DAY
BSPEED	AVERAGE BARGE SPEED
DESIGN	DESIGN COST FOR TANK T OF MATERIAL TYPE M
DIST	DISTANCE FROM PORT P TO LAUNCH SITE IN MILES
FABRICATE	FABRICATION COST OF TANK T OF MATERIAL M
FREQ	TOTAL AMOUNT OF FUEL REQUIRED FOR PAYLOAD OF WEIGHT WT
FUELCOST	COST OF FUEL FOR PAYLOAD OF WEIGHT WT
INSPECT	INSPECTION TIME FOR TANK T OF MATERIAL TYPE M
MCOST	COST PER POUND OF MATERIAL TYPE M
MISYR	MISSIONS PER YEAR
MWT	WEIGHT OF MATERIAL TYPE M USED IN ONE TANK
NEWAMT	REQUIRED FUEL PLUS ADDITIONAL FUEL
NMTO1	MILES TO RETRIEVE FIRST STAGE
NMTO2	MILES TO RETRIEVE SECOND STAGE
NUM	NUMBER OF SUBCALIBUR ROCKETS
NUMMIS	TOTAL NUMBER OF MISSIONS
OPCOST	TOTAL OPERATING COSTS AT PORT P
OVHEAD	OVERHEAD COST FOR TANK T OF MATERIAL TYPE M
PERS	NUMBER OF PERSONNEL
PERSCOST	PERSONNEL COSTS
PREPRO	PREPRODUCTION COST FOR TANK T OF MATERIAL TYPE M
PRICE	BEST PRICE PER KG OF FUEL F AT PORT P
RATE	RATE PER HOUR FOR INSPECTION OF TYPE M MATERIAL
RD	RESEARCH AND DEVELOPMENT COST PER MISSION FOR TANKS
RDAMT	AMOUNT OF MATERIAL TYPE M USED IN R AND D OF TANK T
RDCOST	RESEARCH AND DEVELOPMENT COST FOR TANK T OF MATERIAL M
RECOVERY	RECOVERY AND WASH OFF COST FOR TYPE M OF TANK T
REFURB	REFURBISHMENT COST FOR TANK T OF MATERIAL M
REPAIR	REPAIR COST FOR TANK T OF MATERIAL TYPE M
REPORT1	PORT COSTS PER MISSION FOR 12 MISSIONS PER YEAR
REPORT10	OVERHEAD COSTS PER MISSION
REPORT11	REFURBISHMENT COSTS PER MISSION
REPORT12	OVERHEAD COSTS PER MISSION
REPORT13	TANK COSTS PER MISSION
REPORT14	TANK COSTS PER MISSION
REPORT15	OPERATING COSTS AT PORT P FOR THIS MISSION
REPORT16	OPERATING COSTS AT PORT P FOR THIS MISSION
REPORT2	NUMBER OF TANKS FOR 12 MISSIONS PER YEAR
REPORT3	PORT COSTS PER MISSION FOR 72 MISSIONS PER YEAR

PARAMETERS (Continued)

REPORT4	NUMBER OF TANKS FOR 72 MISSIONS PER YEAR
REPORT5	RESEARCH AND DEVELOPMENT COSTS PER MISSION
REPORT6	RESEARCH AND DEVELOPMENT COSTS PER MISSION
REPORT7	PORT COSTS PER LB FOR TWELVE MISSIONS PER YEAR
REPORT8	PORT COSTS PER LB FOR 72 MISSIONS PER YEAR
REPORT9	REFURBISHMENT COSTS PER MISSION
REUSE	NUMBER OF REUSES OF TANKS
SALARY	AVERAGE ANNUAL SALARY
TANK	NUMBER OF TANKS OF TYPE T REQUIRED PER ROCKET
TDREQ	ADDITIONAL FLUID REQUIREMENTS FOR TIME DELAY
TEST	PROTOTYPE AND TEST COST FOR TANK OF MATERIAL TYPE M
TRANSCOST	COST OF TRANSPORTATION
UNITCOST	UNIT PRODUCTION COST FOR TANK T OF MATERIAL M
UTEST	UNIT TEST COST FOR TANK T OF MATERIAL TYPE M
WT	PAYLOAD WEIGHT

VARIABLES

OVH	TOTAL OVERHEAD COSTS FOR TANKS PER MISSION PER YEAR
REF	TOTAL RECOVERY AND REFURBISHMENT COSTS FOR THIS MISSION
TANKS	COST OF TANKS FOR THIS MISSION
TOTCOST	TOTAL COST OF TANKS
X	NUMBER OF TANKS TYPE T OF MATERIAL M

EQUATIONS

OVERHEAD	TOTAL OVERHEAD COSTS FOR TANKS PER MISSION PER YEAR
REFURBISH	TOTAL RECOVERY AND REFURBISHMENT COSTS FOR THIS MISSION
REQTANKS	NUMBER OF TANKS OF TYPE T REQUIRED FOR THE MISSION
TANKCOST	TOTAL COST OF TANKS
TCOST	COST OF TANKS FOR THIS MISSION

MODELS

SSTS

APPENDIX B

SEALAR SPACE TRANSPORTATION SYSTEM REPORTS FOR TANK AND OP COSTS

---- 438 PARAMETER REPORT5 RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 754586, TWO REUSES 754586, FIVE REUSE 754586,
TEN REUSES 754586, 25 REUSES 754586

---- 438 PARAMETER REPORT2 NUMBER OF TANKS FOR 12 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 PEUSES
MARAGING.RP1	1	1	1	1	1
MARAGING.LOX1	1	1	1	1	1
MARAGING.LOX2	1	1	1	1	1
MARAGING.LH2	1	1	1	1	1
MARAGING.HEL1	1	1	1	1	1
MARAGING.HEL2	1	1	1	1	1

---- 438 PARAMETER REPORT13 TANK COSTS PER MISSION

ONE REUSE 4945400, TWO REUSES 2472700, FIVE REUSE 989080,
TEN REUSES 494540, 25 REUSES 197816

---- 438 PARAMETER REPORT15 OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2921946	2921946	2921946	2921946	29219[illegible]
SANDIEGO	2746024	2746024	2746024	2746024	2746024
GALVESTON	2778370	2778370	2778370	2778370	2778370
JACKSONVIL	2757267	2[illegible]7267	2757267	2757267	2757267

---- 438 PARAMETER REPORT9 REFURBISHMENT COSTS PER MISSION

ONE REUSE 65900, TWO REUSES 65900, FIVE REUSE 65900,
TEN REUSES 65900, 25 REUSES 65900

---- 438 PARAMETER REPORT10 OVERHEAD COSTS PER MISSION

ONE REUSE 5833, TWO REUSES 5833, FIVE REUSE 5833,
TEN REUSES 5833, 25 REUSES 5833

---- 438 PARAMETER REPORT1 PORT COSTS PER MISSION FOR 12 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	8693665	6220965	4737345	4242805	3946081
SANDIEGO	8517744	6045044	4561424	4066884	3770160
GALVESTON	8550089	6077389	4593769	4099229	3802505
JACKSONVIL	8[illegible]28987	6056287	4572667	4078127	3781403

SEALAR SPACE TRANSPORTATION SYSTEM REPORTS FOR TANK AND OP COSTS

---- 438 PARAMETER REPORT7 PORT COSTS PER LB FOR TWELVE MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	869	622	474	424	395
SANDIEGO	852	605	456	407	377
GALVESTON	855	608	459	410	380
JACKSONVIL	853	606	457	408	378

---- 440 PARAMETER REPORT6 RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 754586, TWO REUSES 754586, FIVE REUSE 754586,
TEN REUSES 754586, 25 REUSES 754586

---- 440 PARAMETER REPORT4 NUMBER OF TANKS FOR 72 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
MARAGING.RP1	1	1	1	1	1
MARAGING.LOX1	1	1	1	1	1
MARAGING.LOX2	1	1	1	1	1
MARAGING.LH2	1	1	1	1	1
MARAGING.HEL1	1	1	1	1	1
MARAGING.HEL2	1	1	1	1	1

---- 440 PARAMETER REPORT14 TANK COSTS PER MISSION

ONE REUSE 4945400, TWO REUSES 2472700, FIVE REUSE 989080,
TEN REUSES 494540, 25 REUSES 197816

---- 440 PARAMETER REPORT16 OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2791233	2791233	2791233	2791233	2791233
SANDIEGO	2717022	2717022	2717022	2717022	2717022
GALVESTON	2754415	2754415	2754415	2754415	2754415
JACKSONVIL	2733720	2733720	2733720	2733720	2733720

---- 440 PARAMETER REPORT11 REFURBISHMENT COSTS PER MISSION

ONE REUSE 65900, TWO REUSES 65900, FIVE REUSE 65900,
TEN REUSES 65900, 25 REUSES 65900

---- 440 PARAMETER REPORT12 OVERHEAD COSTS PER MISSION

ONE REUSE 972, TWO REUSES 972, FIVE REUSE 972,
TEN REUSES 972, 25 REUSES 972

SEALAR SPACE TRANSPORTATION SYSTEM REPORTS FOR TANK AND OP COSTS

---- 440 PARAMETER REPORT3 PORT COSTS PER MISSION FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	8558091	6085391	4601771	4107231	3810507
SANDIEGO	8483880	6011180	4527560	4033020	3736296
GALVESTON	8521273	6048573	4564953	4070413	3773689
JACKSONVIL	8500578	6027878	4544258	4049718	3752994

---- 440 PARAMETER REPORT8 PORT COSTS PER LB FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	856	609	460	411	381
SANDIEGO	848	601	453	403	374
GALVESTON	852	605	456	407	377
JACKSONVIL	850	603	454	405	375

APPENDIX C

SSTS TANK AND OP COSTS WHEN PRICE OF MARAGING STEEL IS INCREASED SIGNIFICANTLY

---- 498 PARAMETER REPORT5 RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 11747744, TWO REUSES 11747744, FIVE REUSE 11747744,
TEN REUSES 11747744, 25 REUSES 11747744

---- 498 PARAMETER REPORT2 NUMBER OF TANKS FOR 12 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
CRYOSTRCH.RP1					1
CRYOSTRCH.LOX1	1	1	1	1	1
CRYOSTRCH.LOX2	1	1	1	1	1
CRYOSTRCH.LH2		1	1	1	1
CRYOSTRCH.HEL2				1	1
TITANIUM .RP1	1	1	1	1	
TITANIUM .LH2	1				
TITANIUM .HEL1	1	1	1	1	1
TITANIUM .HEL2	1	1	1		

---- 498 PARAMETER REPORT13 TANK COSTS PER MISSION

ONE REUSE 6736800, TWO REUSES 3375100, FIVE REUSE 1350040,
TEN REUSES 675970, 25 REUSES 272588

---- 498 PARAMETER REPORT15 OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2921946	2921946	2921946	2921946	2921946
SANDIEGO	2746024	2746024	2746024	2746024	2746024
GALVESTON	2778370	2778370	2778370	2778370	2778370
JACKSONVIL	2757267	2757267	2757267	275726	2757267

---- 498 PARAMETER REPORT9 REFURBISHMENT COSTS PER MISSION

ONE REUSE 83080, TWO REUSES 72110, FIVE REUSE 72110,
TEN REUSES 71015, 25 REUSES 65525

---- 498 PARAMETER REPORT10 OVERHEAD COSTS PER MISSION

ONE REUSE 2667, TWO REUSES 2667, FIVE REUSE 2667,
TEN REUSES 2792, 25 REUSES 2792

---- 498 PARAMETER REPORT1 PORT COSTS PER MISSION FOR 12 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	21492237	18119567	16094507	15419467	15010595
SANDIEGO	21316315	17943645	15918585	15243545	14834673
GALVESTON	21348661	17975991	15950931	15275891	14867019
JACKSONVIL	21327558	17954888	15929828	15254788	14845916

SSTS TANK AND OP COSTS WHEN PRICE OF MARAGING STEEL IS INCREASED SIGNIFICANTLY

---- 498 PARAMETER REPORT7 PORT COSTS PER LB FOR TWELVE MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	2149	1812	1609	1542	1501
SANDIEGO	2132	1794	1592	1524	1483
GALVESTON	2135	1798	1595	1528	1487
JACKSONVIL	2133	1795	1593	1525	1485

---- 500 PARAMETER REPORT6 RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 11747744, TWO REUSES 11747744, FIVE REUSE 11747744,
TEN REUSES 11747744, 25 REUSES 11747744

- - 500 PARAMETER REPORT4 NUMBER OF TANKS FOR 72 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
CRYOSTRCH.RP1					1
CRYOSTRCH.LOX1	1	1	1	1	1
CRYOSTRCH.LOX2	1	1	1	1	1
CRYOSTRCH.LH2		1	1	1	1
CRYOSTRCH.HEL2				1	1
TITANIUM .RP1	1	1	1	1	
TITANIUM .LH2	1				
TITANIUM .HEL1	1	1	1	1	1
TITANIUM .HEL2	1	1	1		

---- 500 PARAMETER REPORT14 TANK COSTS PER MISSION

ONE REUSE 6736800, TWO REUSES 3375100, FIVE REUSE 1350040,
TEN REUSES 675970, 25 REUSES 272588

---- 500 PARAMETER REPORT16 OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2921946	2921946	2921946	2921946	2921946
SANDIEGO	2746024	2746024	2746024	2746024	2746024
GALVESTON	2773370	2778370	2778370	2778370	2778370
JACKSONVIL	2757267	2757267	2757267	2757267	2757267

---- 500 PARAMETER REPORT11 REFURBISHMENT COSTS PER MISSION

ONE REUSE 83080, TWO REUSES 72110, FIVE REUSE 72110,
TEN REUSES 71015, 25 REUSES 65525

SSTS TANK AND OP COSTS WHEN PRICE OF MARAGING STEEL IS INCREASED SIGNIFICANTLY

---- 500 PARAMETER REPORT12 OVERHEAD COSTS PER MISSION

ONE REUSE 444, TWO REUSES 444, FIVE REUSE 444,
TEN REUSES 465, 25 REUSES 465

---- 500 PARAMETER REPORT3 PORT COSTS PER MISSION FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	21490014	18117344	16092284	15417140	15008268
SANDIEGO	21314092	17941422	15916362	15241218	14832346
GALVESTON	21346438	17973768	15948708	15273564	14864692
JACKSONVIL	21325335	1795[illegible]	15927605	15252461	14843589

---- 500 PARAMETER REPORT8 PORT COSTS PER LB FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	2149	1812	1609	1542	1501
SANDIEGO	2131	1794	1592	1524	1483
GALVESTON	2135	1797	1595	1527	1486
JACKSONVIL	2133	1795	1593	1525	1484

APPENDIX D

SSTS TANK AND OP COSTS WHEN COMPOSITES WERE CHEAP AND MARAGING STEEL WAS HIGH

---- 443 PARAMETER REPORT5 RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 11448899, TWO REUSES 11448899, FIVE REUSE 11448899,
TEN REUSES 11448899, 25 REUSES 11448899

---- 443 PARAMETER REPORT2 NUMBER OF TANKS FOR 12 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
CRYOSTRCH .RP1					1
CRYOSTRCH .LOX2	1	1	1	1	1
CRYOSTRCH .LH2		1	1	1	1
CRYOSTRCH .HEL2					1
COMPOSITES.LOX1	1	1	1	1	1
COMPOSITES.HEL1	1	1	1	1	1
COMPOSITES.HEL2	1	1	1	1	
TITANIUM .RP1	1	1	1	1	
TITANIUM .LH2	1				

---- 443 PARAMETER REPORT13 TANK COSTS PER MISSION

ONE REUSE 4335500, TWO REUSES 2174450, FIVE REUSE 869780,
TEN REUSES 434890, 25 REUSES 178160

---- 443 PARAMETER REPORT15 OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2921946	2921946	2921946	2921946	2921946
SANDIEGO	2746024	2746024	2746024	2746024	2746024
GALVESTON	2778370	2778370	2778370	2778370	2778370
JACKSONVIL	2757267	2757267	2757267	2757267	2757267

---- 443 PARAMETER REPORT9 REFURBISHMENT COSTS PER MISSION

ONE REUSE 100880, TWO REUSES 89910, FIVE REUSE 89910,
TEN REUSES 89910, 25 REUSES 81855

---- 443 PARAMETER REPORT10 OVERHEAD COSTS PER MISSION

ONE REUSE 7083, TWO REUSES 7083, FIVE REUSE 7083,
TEN REUSES 7083, 25 REUSES 6042

---- 443 PARAMETER REPORT1 PORT COSTS PER MISSION FOR 12 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	18814308	16642288	15337618	14902728	14636902
SANDIEGO	18638387	16466367	15161697	14726807	14460980
GALVESTON	18670732	16498712	15194042	14759152	14493326
JACKSONVIL	18649630	16477610	15172940	14738050	14472223

SSTS TANK AND OP COSTS WHEN COMPOSITES WERE CHEAP AND MARAGING STEEL WAS HIGH

---- 443 PARAMETER REPORT7 PORT COSTS PER LB FOR TWELVE MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	1881	1664	1534	1490	1464
SANDIEGO	1864	1647	1516	1473	1446
GALVESTON	1867	1650	1519	1476	1449
JACKSONVIL	1865	1648	1517	1474	1447

---- 445 PARAMETER REPORT6 RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 11448899, TWO REUSES 11448899, FIVE REUSE 11448899,
TEN REUSES 11448899, 25 REUSES 11448899

---- 445 PARAMETER REPORT4 NUMBER OF TANKS FOR 72 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
CRYOSTRCH .RP1					1
CRYOSTRCH .LOX2	1	1	1	1	1
CRYOSTRCH .LH2		1	1	1	1
CRYOSTRCH .HEL2					1
COMPOSITES.LOX1	1	1	1	1	1
COMPOSITES.HEL1	1	1	1	1	1
COMPOSITES.HEL2	1	1	1	1	
TITANIUM .RP1	1	1	1	1	
TITANIUM .LH2	1				

---- 445 PARAMETER REPORT14 TANK COSTS PER MISSION

ONE REUSE 4335500, TWO REUSES 2174450, FIVE REUSE 869780,
TEN REUSES 434890, 25 REUSES 178160

---- 445 PARAMETER REPORT16 OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2791233	2791233	2791233	2791233	2791233
SANDIEGO	2717022	2717022	2717022	2717022	2717022
GALVESTON	2754415	2754415	2754415	2754415	2754415
JACKSONVIL	2733720	2733720	2733720	2733720	2733720

---- 445 PARAMETER REPORT11 REFURBISHMENT COSTS PER MISSION

ONE REUSE 100880, TWO REUSES 89910, FIVE REUSE 89910,
TEN REUSES 89910, 25 REUSES 81855

SSTS TANK AND OP COSTS WHEN COMPOSITES WERE CHEAP AND MARAGING STEEL WAS HIGH

---- 445 PARAMETER REPORT12 OVERHEAD COSTS PER MISSION

ONE REUSE 1181, TWO REUSES 1181, FIVE REUSE 1181,
TEN REUSES 1181, 25 REUSES 1007

---- 445 PARAMETER REPORT3 PORT COSTS PER MISSION FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	18677693	16505673	15201003	14766113	14501154
SANDIEGO	18603481	16431461	15126791	14691901	14426943
GALVESTON	18640874	16468854	15164184	14729294	14464336
JACKSONVIL	18620180	16448160	15143490	14708600	14443641

---- 445 PARAMETER REPORT8 PORT COSTS PER LB FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	1868	1651	1520	1477	1450
SANDIEGO	1860	1643	1513	1469	1443
GALVESTON	1864	1647	1516	1473	1446
JACKSONVIL	1862	1645	1514	1471	1444

APPENDIX E

SSTS TANK AND OP COSTS WHEN RESEARCH & DEVELOPMENT COSTS ARE FOR TANKS SPECIFIED BY MODEL

---- 443 PARAMETER REPORT5 RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 130042, TWO REUSES 130042, FIVE REUSE 130042,
TEN REUSES 130042, 25 REUSES 130042

---- 443 PARAMETER REPORT2 NUMBER OF TANKS FOR 12 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
MARAGING.RP1	1	1	1	1	1
MARAGING.LOX1	1	1	1	1	1
MARAGING.LOX2	1	1	1	1	1
MARAGING.LH2	1	1	1	1	1
MARAGING.HEL1	1	1	1	1	1
MARAGING.HEL2	1	1	1	1	1

---- 443 PARAMETER REPORT13 TANK COSTS PER MISSION

ONE REUSE 4945400, TWO REUSES 2472700, FIVE REUSE 989080,
TEN REUSES 494540, 25 REUSES 197816

---- 443 PARAMETER REPORT15 OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2921946	2921946	2921946	2921946	2921946
SANDIEGO	2746024	2746024	2746024	2746024	2746024
GALVESTON	2778370	2778370	2778370	2778370	2778370
JACKSONVIL	2757267	2757267	2757267	2757267	2757267

---- 443 PARAMETER REPORT9 REFURBISHMENT COSTS PER MISSION

ONE REUSE 65900, TWO REUSES 65900, FIVE REUSE 65900,
TEN REUSES 65900, 25 REUSES 65900

---- 443 PARAMETER REPORT10 OVERHEAD COSTS PER MISSION

ONE REUSE 5833, TWO REUSES 5833, FIVE REUSE 5833,
TEN REUSES 5833, 25 REUSES 5833

---- 443 PARAMETER REPORT1 PORT COSTS PER MISSION FOR 12 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	8069121	5596421	4112801	3618261	3321537
SANDIEGO	7893200	5420500	3936880	3442340	3145616
GALVESTON	7925545	5452845	3969225	3474685	3177961
JACKSONVIL	7904443	5431743	3948123	3453583	3156859

SSTS TANK AND OP COSTS WHEN RESEARCH & DEVELOPMENT COSTS ARE FOR TANKS SPECIFIED BY MODEL

---- 443 PARAMETER REPORT7 PORT COSTS PER LB FOR TWELVE MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	807	560	411	362	332
SANDIEGO	789	542	394	344	315
GALVESTON	793	545	397	347	318
JACKSONVIL	790	543	395	345	316

---- 445 PARAMETER REPORT6 RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 130042, TWO REUSES 130042, FIVE REUSE 130042,
TEN REUSES 130042, 25 REUSES 130042

---- 445 PARAMETER REPORT4 NUMBER OF TANKS FOR 72 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
MARAGING.RP1	1	1	1	1	1
MARAGING.LOX1	1	1	1	1	1
MARAGING.LOX2	1	1	1	1	1
MARAGING.LH2	1	1	1	1	1
MARAGING.HEL1	1	1	1	1	1
MARAGING.HEL2	1	1	1	1	1

---- 445 PARAMETER REPORT14 TANK COSTS PER MISSION

ONE REUSE 4945400, TWO REUSES 2472700, FIVE REUSE 989080,
TEN REUSES 494540, 25 REUSES 197816

---- 445 PARAMETER REPORT16 OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2791233	2791233	2791233	2791233	2791233
SANDIEGO	2717022	2717022	2717022	2717022	2717022
GALVESTON	2754415	2754415	2754415	2754415	2754415
JACKSONVIL	2733720	2733720	2733720	2733720	2733720

---- 445 PARAMETER REPORT11 REFURBISHMENT COSTS PER MISSION

ONE REUSE 65900, TWO REUSES 65900, FIVE REUSE 65900,
TEN REUSES 65900, 25 REUSES 65900

---- 445 PARAMETER REPORT12 OVERHEAD COSTS PER MISSION

ONE REUSE 972, TWO REUSES 972, FIVE REUSE 972,
TEN REUSES 972, 25 REUSES 972

SSTS TANK AND OP COSTS WHEN RESEARCH & DEVELOPMENT COSTS ARE FOR TANKS SPECIFIED BY MODEL

---- 445 PARAMETER REPORT3 PORT COSTS PER MISSION FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	7933547	5460847	3977227	3482687	3185963
SANDIEGO	7859336	5386636	3903016	3408476	3111752
GALVESTON	7896729	5424029	3940409	3445869	3149145
JACKSONVIL	7876034	5403334	3919714	3425174	3128450

---- 445 PARAMETER REPORT8 PORT COSTS PER LB FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	793	546	398	348	319
SANDIEGO	786	539	390	341	311
GALVESTON	790	542	394	345	315
JACKSONVIL	788	540	392	343	313

SSTS COSTS WHEN R&D WAS FOR SPECIFIED TANKS AND MARAGING STEEL WAS HIGH

---- 443 PARAMETER REPORT5 RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 177884, TWO REUSES 176686, FIVE REUSE 176686,
TEN REUSES 176686, 25 REUSES 178436

---- 443 PARAMETER REPORT2 NUMBER OF TANKS FOR 12 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
CRYOSTRCH.RP1					1
CRYOSTRCH.LOX1	1	1	1	1	1
CRYOSTRCH.LOX2	1	1	1	1	1
CRYOSTRCH.LH2		1	1	1	1
TITANIUM .RP1	1	1	1	1	
TITANIUM .LH2	1				
TITANIUM .HEL1	1	1	1	1	1
TITANIUM .HEL2	1	1	1	1	1

---- 443 PARAMETER REPORT13 TANK COSTS PER MISSION

ONE REUSE 6736800, TWO REUSES 3375100, FIVE REUSE 1350040,
TEN REUSES 675020, 25 REUSES 272208

---- 443 PARAMETER REPORT15 OPERATI _ COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2921946	2921946	2921946	2921946	2921946
SANDIEGO	2746024	2746024	2746024	2746024	2746024
GALVESTON	2778370	2778370	2778370	2778370	2778370
JACKSONVIL	2757267	2757267	2757267	2757267	2757267

---- 443 PARAMETER REPORT9 REFURBISHMENT COSTS PER MISSION

ONE REUSE 83080, TWO REUSES 72110, FIVE REUSE 72110,
TEN REUSES 72110, 25 REUSES 66620

---- 443 PARAMETER REPORT10 OVERHEAD COSTS PER MISSION

ONE REUSE 2667, TWO REUSES 2667, FIVE REUSE 2667,
TEN REUSES 2667, 25 REUSES 2667

---- 443 PARAMETER REPORT1 PORT COSTS PER MISSION FOR 12 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	9922377	6548509	4523449	3848429	3441877
SANDIEGO	9746455	6372587	4347527	3672507	3265955
GALVESTON	9778801	6404933	4379873	3704853	3298301
JACKSONVIL	9757698	6383830	4358770	3683750	3277198

SSTS COSTS WHEN R&D WAS FOR SPECIFIED TANKS AND MARAGING STEEL WAS HIGH

---- 443 PARAMETER REPORT7 PORT COSTS PER LB FOR TWELVE MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	992	655	452	385	344
SANDIEGO	975	637	435	367	327
GALVESTON	978	640	438	370	330
JACKSONVIL	976	638	436	368	328

---- 445 PARAMETER REPORT6 RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 177884, TWO REUSES 176686, FIVE REUSE 176686,
TEN REUSES 176686, 25 REUSES 178436

---- 445 PARAMETER REPORT4 NUMBER OF TANKS FOR 72 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
CRYOSTRCH.RP1					1
CRYOSTRCH.LOX1	1	1	1	1	1
CRYOSTRCH.LOX2	1	1	1	1	1
CRYOSTRCH.LH2		1	1	1	1
TITANIUM .RP1	1	1	1	1	
TITANIUM .LH2	1				
TITANIUM .HEL1	1	1	1	1	1
TITANIUM .HEL2	1	1	1	1	1

---- 445 PARAMETER REPORT14 TANK COSTS PER MISSION

ONE REUSE 6736000, TWO REUSES 3375100, FIVE REUSE 1350040,
TEN REUSES 675020, 25 REUSES 272208

---- 445 PARAMETER REPORT16 OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2791233	2791233	2791233	2791233	2791233
SANDIEGO	2717022	2717022	2717022	2717022	2717022
GALVESTON	2754415	2754415	2754415	2754415	2754415
JACKSONVIL	2733720	2733720	2733720	2733720	2733720

---- 445 PARAMETER REPORT11 REFURBISHMENT COSTS PER MISSION

ONE REUSE 83080, TWO REUSES 72110, FIVE REUSE 72110,
TEN REUSES 72110, 25 REUSES 66620

---- 445 PARAMETER REPORT12 OVERHEAD COSTS PER MISSION

ONE REUSE 444, TWO REUSES 444, FIVE REUSE 444,
TEN REUSES 444, 25 REUSES 444

SSTS COSTS WHEN R&D WAS FOR SPECIFIED TANKS AND MARAGING STEEL WAS HIGH

---- 445 PARAMETER REPORT3 PORT COSTS PER MISSION FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	9789442	6415574	4390514	3715494	3308942
SANDIEGO	9715230	6341362	4316302	3641282	3234730
GALVESTON	9752623	6378755	4353695	3678675	3272123
JACKSONVIL	9731929	6358061	4333001	3657981	3251429

---- 445 PARAMETER REPORT8 PORT COSTS PER LB FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	979	642	439	372	331
SANDIEGO	972	634	432	364	323
GALVESTON	975	638	435	368	327
JACKSONVIL	973	636	433	366	325

SSTS COSTS WHEN R&D WAS FOR SPECIFIED TANKS, COMPOSITES WERE LOW & MARAGING STEEL WAS HIGH

---- 443 PARAMETER REPORT5 RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 86005, TWO REUSES 84807, FIVE REUSE 62838,
TEN REUSES 62838, 25 REUSES 62838

---- 443 PARAMETER REPORT2 NUMBER OF TANKS FOR 12 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
CRYOSTRCH .LOX2	1	1	1	1	1
CRYOSTRCH .LH2		1	1	1	1
COMPOSITES.RP1			1	1	1
COMPOSITES.LOX1	1	1	1	1	1
COMPOSITES.HEL1	1	1	1	1	1
COMPOSITES.HEL2	1	1	1	1	1
TITANIUM .RP1	1	1			
TITANIUM .LH2	1				

---- 443 PARAMETER REPORT13 TANK COSTS PER MISSION

ONE REUSE 4335500, TWO REUSES 2174450, FIVE REUSE 875320,
TEN REUSES 437660, 25 REUSES 175064

---- 443 PARAMETER REPORT15 OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2921946	2921946	2921946	2921946	2921946
SANDIEGO	2746024	2746024	2746024	2746024	2746024
GALVESTON	2778370	2778370	2778370	2778370	2778370
JACKSONVIL	2757267	2757267	2757267	2757267	2757267

---- 443 PARAMETER REPORT9 REFURBISHMENT COSTS PER MISSION

ONE REUSE 100880, TWO REUSES 89910, FIVE REUSE 96550,
TEN REUSES 96550, 25 REUSES 96550

---- 443 PARAMETER REPORT10 OVERHEAD COSTS PER MISSION

ONE REUSE 7083, TWO REUSES 7083, FIVE REUSE 11250,
TEN REUSES 11250, 25 REUSES 11250

---- 443 PARAMETER REPORT1 PORT COSTS PER MISSION FOR 12 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	7451414	5278196	3967904	3530244	3267648
SANDIEGO	7275493	5102275	3791982	3354322	3091726
GALVESTON	7307838	5134620	3824328	3386668	3124072
JACKSONVIL	7286736	5113518	3803225	3365565	3102969

SSTS COSTS WHEN R&D WAS FOR SPECIFIED TANKS, COMPOSITES WERE LOW & MARAGING STEEL WAS HIGH

---- 443 PARAMETER REPORT7 PORT COSTS PER LB FOR TWELVE MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	745	528	397	353	327
SANDIEGO	728	510	379	335	309
GALVESTON	731	513	382	339	312
JACKSONVIL	729	511	380	337	310

---- 445 PARAMETER REPORT6 RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 86005, TWO REUSES 62838, FIVE REUSE 62838,
TEN REUSES 62838, 25 REUSES 62838

---- 445 PARAMETER REPORT4 NUMBER OF TANKS FOR 72 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
CRYOSTRCH .LOX2	1	1	1	1	1
CRYOSTRCH .LH2		1	1	1	1
COMPOSITES.RP1		1	1	1	1
COMPOSITES.LOX1	1	1	1	1	1
COMPOSITES.HEL1	1	1	1	1	1
COMPOSITES.HEL2	1	1	1	1	1
TITANIUM .RP1	1				
TITANIUM .LH2	1				

---- 445 PARAMETER REPORT14 TANK COSTS PER MISSION

ONE REUSE 4335500, TWO REUSES 2188300, FIVE REUSE 875320,
TEN REUSES 437660, 25 REUSES 175064

---- 445 PARAMETER REPORT16 OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2791233	2791233	2791233	2791233	2791233
SANDIEGO	2717022	2717022	2717022	2717022	2717022
GALVESTON	2754415	2754415	2754415	2754415	2754415
JACKSONVIL	2733720	2733720	2733720	2733720	2733720

---- 445 PARAMETER REPORT11 REFURBISHMENT COSTS PER MISSION

ONE REUSE 100880, TWO REUSES 96550, FIVE REUSE 96550,
TEN REUSES 96550, 25 REUSES 96550

---- 445 PARAMETER REPORT12 OVERHEAD COSTS PER MISSION

ONE REUSE 1181, TWO REUSES 1875, FIVE REUSE 1875,
TEN REUSES 1875, 25 REUSES 1875

SSTS COSTS WHEN R&D WAS FOR SPECIFIED TANKS, COMPOSITES WERE LOW & MARAGING STEEL WAS HIGH

---- 445 PARAMETER REPORT3 PORT COSTS PER MISSION FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	7314799	5140796	3827816	3390156	3127560
SANDIEGO	7240587	5066585	3753605	3315945	3053349
GALVESTON	7277980	5103978	3790998	3353338	3090742
JACKSONVIL	7257286	5083283	3770303	3332643	3070047

---- 445 PARAMETER REPORT8 PORT COSTS PER LB FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	731	514	383	339	313
SANDIEGO	724	507	375	332	305
GALVESTON	728	510	379	335	309
JACKSONVIL	726	508	377	333	307

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